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TRANSMITTAL LETTER AND CERTIFICATE OF MAILING

To: Commissioner of Patents and Trademarks
Washington, D.C. 20231
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The following enumerated items accompany this transmittal letter and are being submitted for the matter identified in the above caption.

1. Transmittal Letter with Certificate of Mailing included.
2. PTO Return Postcard Receipt
3. Check in the Amount of \$1,730
4. Fee Transmittal
5. New patent application (title page plus 53 pages, including claims 1-51 & Abstract)
6. Executed Declaration
7. Petition under 37 CFR 1.84(a)(2)
8. 20 sheets of formal drawings (Figs. 1-18) (In triplicate)
9. Information Disclosure Statement, Form 1449 and copies of cited references
10. Assignment w/Recordation Cover Sheet

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR LETTERS PATENT

**Methods and Systems for Animating Facial Features,
and Methods and Systems for Expression
Transformation**

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1 **TECHNICAL FIELD**

2 This invention relates to methods and systems for modeling and rendering
3 for realistic facial animation. In particular, the invention concerns methods and
4 systems for facial image processing.

5
6 **BACKGROUND**

7 The field of computer graphics involves rendering various objects so that
8 the objects can be displayed on a computer display for a user. For example,
9 computer games typically involve computer graphics applications that generate
10 and render computer objects for display on a computer monitor or television.
11 Modeling and rendering realistic images is a continuing challenge for those in the
12 computer graphics field. One particularly challenging area within the computer
13 graphics field pertains to the rendering of realistic facial images. As an example, a
14 particular computer graphics application may render a display of an individual
15 engaging in a conversation. Often times, the ultimately rendered image of this
16 individual is very obviously a computer-rendered image that greatly differs from a
17 real individual.

18 Modeling and rendering realistic faces and facial expressions is a
19 particularly difficult task for two primary reasons. First, the human skin has
20 reflectance properties that are not well modeled by the various shading models that
21 are available for use. For example, the well-known Phong model does not model
22 human skin very well. Second, when rendering facial expressions, the slightest
23 deviation from what would be perceived as "real" facial movement is perceived by
24 even the casual viewer as being incorrect. While current facial motion capture
25 systems can be used to create quite convincing facial animation, the captured

1 motion is much less convincing, and frequently very strange, when applied to
2 another face. For example, if a person provides a sampling of their facial
3 movements, then animating their specific facial movements is not difficult
4 considering that the face from which the movements originated is the same face.
5 Because of this, there will be movement characteristics that are the same or very
6 similar between expressions. Translating this person's facial movements to
7 another person's face, however, is not often times convincing because of, among
8 other things, the inherent differences between the two faces (e.g. size and shape of
9 the face).

10 Accordingly, this invention arose out of concerns associated with providing
11 improved systems and methods for modeling texture and reflectance of human
12 skin. The invention also arose out of concerns associated with providing systems
13 and methods for reusing facial motion capture data by transforming one person's
14 facial motions into another person's facial motions.

15 16 **SUMMARY**

17 The illustrated and described embodiments propose inventive techniques
18 for capturing data that describes 3-dimensional (3-D) aspects of a face,
19 transforming facial motion from one individual to another in a realistic manner,
20 and modeling skin reflectance.

21 In the described embodiment, a human subject is provided and multiple
22 different light sources are utilized to illuminate the subject's face. One of the light
23 sources is a structured light source that projects a pattern onto the subject's face.
24 This structured light source enables one or more cameras to capture data that
25 describes 3-D aspects of the subject's face. Another light source is provided and is

used to illuminate the subject's face. This other light source is sufficient to enable various reflectance properties of the subject's face to be ascertained. The other light source is used in conjunction with polarizing filters so that the specular component of the face's reflectance is eliminated, i.e. only the diffuse component is captured by the camera. The use of the multiple different light sources enables both structure and reflectance properties of a face to be ascertained at the same time. By selecting the light sources carefully, for example, by making the light sources narrowband and using matching narrowband filters on the cameras, the influence of ambient sources of illumination can be eliminated.

Out of the described illumination process, two useful items are produced— (1) a range map (or depth map) and (2) an image of the face that does not have the structured light source pattern in it. A 3D surface is derived from the range map and surface normals to the 3D surface are computed. The processing of the range map to define the 3D surface can optionally include a filtering step in which a generic face template is combined with the range map to reject undesirable noise. The computed surface normals and the image of the face are then used to derive an albedo map. An albedo map is a special type of texture map in which each sample describes the diffuse reflectance of the surface of a face at a particular point on the surface. Accordingly, at this point in the process, information has been ascertained that describes the 3D-aspects of a face (i.e. the surface normals), and information that describes the face's reflectance (i.e. the albedo map).

In one embodiment, the information or data that was produced in the illumination process is used to transform facial expressions of one person into facial expressions of another person. In this embodiment, the notion of a code book is introduced and used.

1 is true for every possible different face model. By adding this constraint, the base
2 mesh has a property in that it fits different face models in the same way. In
3 addition, the inventive algorithm utilizes a smoothing functional that is minimized
4 to ensure that there is a good correspondence between the base mesh and the face
5 model.

6 In another embodiment, a reflectance processing technique is provided that
7 gives a measure of the reflectance of the surface of a subject's face. To measure
8 reflectance, the inventive technique separates the reflectance into its diffuse and
9 specular components and focuses on the treatment of the diffuse components.

10 To measure the diffuse component, an albedo map is first defined. The
11 albedo map is defined by first providing a camera and a subject that is illuminated
12 by multiple different light sources. The light sources are filtered by polarizing
13 filters that, in combination with a polarizing filter placed in front of the camera,
14 suppress specular reflection or prevent specular reflection from being recorded. A
15 sequence of images is taken around the subject's head. Each individual image is
16 processed to provide an individual albedo map that corresponds to that image. All
17 of the albedo maps for a particular subject are then combined to provide a single
18 albedo map for the subject's entire face.

19 20 **BRIEF DESCRIPTION OF THE DRAWINGS**

21 Fig. 1 is a high level diagram of a general purpose computer that is suitable
22 for use in implementing the described embodiments.

23 Fig. 2 is a schematic diagram of a system that can be utilized to capture
24 both structural information and reflectance information of a subject's face at the
25 same time.

1 Fig. 3 is a flow diagram that describes an exemplary method for capturing
2 structural information and reflectance information in accordance with the
3 described embodiment.

4 Fig. 4 is a schematic diagram that illustrates an exemplary code book and
5 transformation function in accordance with the described embodiment.

6 Fig. 5 is a flow diagram that illustrates an expression transformation
7 process in accordance with the described embodiment.

8 Fig. 6 is a high level diagram of an exemplary system in which certain
9 principles of the described embodiments can be employed.

10 Fig. 7 is a collection of exemplary color plates that illustrate an exemplary
11 expression transformation in accordance with the described embodiment.

12 Fig. 8 is a color picture that illustrates the process of mapping the same
13 subdivision control mesh to a displaced subdivision surface for different faces.

14 Fig. 9 is a color picture that illustrates exemplary constraints that are
15 utilized to enforce feature correspondence during surface fitting.

16 Fig. 10 is a flow diagram that describes steps in a surface fitting method in
17 accordance with the described embodiment.

18 Fig. 11 is a schematic diagram of an exemplary system that can be
19 employed to build an albedo map for a face in accordance with the described
20 embodiment.

21 Fig. 12 is a color picture of an exemplary albedo map for two photographs
22 that are projected into texture space and corrected for lighting.

23 Fig. 13 is a color picture of an exemplary weighting function that
24 corresponds to the Fig. 12 photographs.

25 Fig. 14 is a color picture of two full albedo maps for two different data sets.

Fig. 15 is a color diagram of the Fig. 14 albedo maps after editing.

Fig. 16 is a collection of color pictures of a face model that is rendered in different orientations and under different lighting conditions.

Fig. 17 is a flow diagram that describes steps in a method for creating an albedo map in accordance with the described embodiment.

Fig. 18 is a flow diagram that describes steps in a method for computing an albedo for a single pixel in accordance with the described embodiment.

DETAILED DESCRIPTION

Overview

Rendering realistic faces and facial expressions requires very good models for the reflectance of skin and the motion of the face. Described below are methods and techniques for modeling, animating, and rendering a face using measured data for geometry, motion, and reflectance that realistically reproduces the appearance of a particular person's face and facial expressions. Because a complete model is built that includes geometry and bi-directional reflectance, the face can be rendered under any illumination and viewing conditions. The described modeling systems and methods create structured face models with correspondences across different faces, which provide a foundation for a variety of facial animation operations.

The inventive embodiments discussed below touch upon each of the parts of the face modeling process. To create a structured, consistent representation of geometry that forms the basis for a face model and that provides a foundation for many further face modeling and rendering operations, inventive aspects extend previous surface fitting techniques to allow a generic face to be conformed to

different individual faces. To create a realistic reflectance model, the first known practical use of recent skin reflectance measurements is made. In addition, newly measured diffuse texture maps have been added using an improved texture capture process. To animate a generic mesh, improved techniques are used to produce surface shapes suitable for high quality rendering.

Exemplary Computer System

Preliminarily, Fig. 1 shows a general example of a desktop computer 130 that can be used in accordance with the described embodiments. Various numbers of computers such as that shown can be used in the context of a distributed computing environment. These computers can be used to render graphics and process images in accordance with the description given below.

Computer 130 includes one or more processors or processing units 132, a system memory 134, and a bus 136 that couples various system components including the system memory 134 to processors 132. The bus 136 represents one or more of any of several types of bus structures, including a memory bus or memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. The system memory 134 includes read only memory (ROM) 138 and random access memory (RAM) 140. A basic input/output system (BIOS) 142, containing the basic routines that help to transfer information between elements within computer 130, such as during start-up, is stored in ROM 138.

Computer 130 further includes a hard disk drive 144 for reading from and writing to a hard disk (not shown), a magnetic disk drive 146 for reading from and writing to a removable magnetic disk 148, and an optical disk drive 150 for

1 reading from or writing to a removable optical disk 152 such as a CD ROM or
2 other optical media. The hard disk drive 144, magnetic disk drive 146, and optical
3 disk drive 150 are connected to the bus 136 by an SCSI interface 154 or some
4 other appropriate peripheral interface. The drives and their associated computer-
5 readable media provide nonvolatile storage of computer-readable instructions, data
6 structures, program modules and other data for computer 130. Although the
7 exemplary environment described herein employs a hard disk, a removable
8 magnetic disk 148 and a removable optical disk 152, it should be appreciated by
9 those skilled in the art that other types of computer-readable media which can
10 store data that is accessible by a computer, such as magnetic cassettes, flash
11 memory cards, digital video disks, random access memories (RAMs), read only
12 memories (ROMs), and the like, may also be used in the exemplary operating
13 environment.

14 A number of program modules may be stored on the hard disk 144,
15 magnetic disk 148, optical disk 152, ROM 138, or RAM 140, including an
16 operating system 158, one or more application programs 160, other program
17 modules 162, and program data 164. A user may enter commands and
18 information into computer 130 through input devices such as a keyboard 166 and a
19 pointing device 168. Other input devices (not shown) may include a microphone,
20 joystick, game pad, satellite dish, scanner, and one or more cameras, or the like.
21 These and other input devices are connected to the processing unit 132 through an
22 interface 170 that is coupled to the bus 136. A monitor 172 or other type of
23 display device is also connected to the bus 136 via an interface, such as a video
24 adapter 174. In addition to the monitor, personal computers typically include other
25 peripheral output devices (not shown) such as speakers and printers.

Computer 130 commonly operates in a networked environment using logical connections to one or more remote computers, such as a remote computer 176. The remote computer 176 may be another personal computer, a server, a router, a network PC, a peer device or other common network node, and typically includes many or all of the elements described above relative to computer 130, although only a memory storage device 178 has been illustrated in Fig. 1. The logical connections depicted in Fig. 1 include a local area network (LAN) 180 and a wide area network (WAN) 182. Such networking environments are commonplace in offices, enterprise-wide computer networks, intranets, and the Internet.

When used in a LAN networking environment, computer 130 is connected to the local network 180 through a network interface or adapter 184. When used in a WAN networking environment, computer 130 typically includes a modem 186 or other means, such as a network interface, for establishing communications over the wide area network 182, such as the Internet. The modem 186, which may be internal or external, is connected to the bus 136 via a serial port interface 156. In a networked environment, program modules depicted relative to the personal computer 130, or portions thereof, may be stored in the remote memory storage device. It will be appreciated that the network connections shown are exemplary and other means of establishing a communications link between the computers may be used.

Generally, the data processors of computer 130 are programmed by means of instructions stored at different times in the various computer-readable storage media of the computer. Programs and operating systems are typically distributed, for example, on floppy disks or CD-ROMs. From there, they are installed or

loaded into the secondary memory of a computer. At execution, they are loaded at least partially into the computer's primary electronic memory. The invention described herein includes these and other various types of computer-readable storage media when such media contain instructions or programs for implementing the steps described below in conjunction with a microprocessor or other data processor. The invention also includes the computer itself when programmed according to the methods and techniques described below.

For purposes of illustration, programs and other executable program components such as the operating system are illustrated herein as discrete blocks, although it is recognized that such programs and components reside at various times in different storage components of the computer, and are executed by the data processor(s) of the computer.

Exemplary System for Capturing Structure and Properties of a Facial Surface

In the past, capturing systems have not been able to capture both facial structure and reflectance properties of a whole face independently at the same time. There are systems that, for example, use structured light to capture the structure of the face--but these systems do not capture properties of the face such as the reflectance. Similarly, there are systems that capture reflectance of the face--but such systems do not capture facial structure. The ability to capture facial structure and reflectance independently at the same time makes it possible to perform additional operations on collected data which is useful in various face rendering and animation operations. One particular example of an exemplary rendering operation is described below. It is to be understood, however, that the information or data that is produced as a result of the system and method described

below can be utilized in various other areas. For example, areas of application include, without limitation, recognition of faces for security, personal user interaction, etc., building realistic face models for animation in games, movies, etc., and allowing a user to easily capture his/her own face for use in interactive entertainment or business communication.

Fig. 2 shows an exemplary system 200 that is suitable for use in simultaneously or contemporaneously capturing facial structure and reflectance properties of a subject's face. The system includes a data-capturing system in the form of one or more cameras, an exemplary one of which is camera 202. Camera 202 can include a CCD image sensor and related circuitry for operating the array, reading images from it, converting the images to digital form, and communicating those images to the computer. The system also includes a facial illumination system in the form of multiple light sources or projectors. In the case where multiple cameras are used, they are genlocked to allow simultaneous capture in time. In the illustrated example, two light sources 204, 206 are utilized. Light source 204 desirably produces a structured pattern that is projected onto the subject's face. Light source 204 can be positioned at any suitable location. This pattern enables structural information or data pertaining to the 3-D shape of the subject's face to be captured by camera 202. Any suitable light source can be used, although a pattern composed of light in the infrared region can be advantageously employed. Light source 206 desirably produces light that enables camera 202 to capture the diffuse component of the face's reflectance property. Light source 206 can be positioned at any suitable location although it has been advantageously placed in line with the camera's lens 202a through, for example, beam splitting techniques. This light source could also be adapted so that it

describes diffuse reflectance properties of the face. This information is then processed by a computerized image processor, such as computer 208, to provide information or data that can be used for further facial animation operations. In the example about to be described, this information comprises 3-dimensional data (3D data) and an albedo map.

Fig. 3 is a flow diagram that describes steps in a method in accordance with this described embodiment. The described method enables information or data that pertains to structure and reflection properties of a face to be collected and processed at the same time. Step 300 illuminates a subject's face with multiple different light sources. An exemplary system for implementing this step is shown in Fig. 2. It will be appreciated that although two exemplary light sources are utilized in the given example, other numbers of light sources can conceivably be used. Step 302 measures range map data (depth map data) and image data from the illumination of step 300. That is, the illumination of step 300 enables the camera to detect light reflectance that is utilized to provide both range map data and image data (i.e. reflectance) that does not contain the structure light source pattern in it. The range map data and image data are provided to computer 208 (Fig. 2) for processing. At this point, step 304 can optionally apply a generic face template to the range map data to reject various noise that can be associated with the range map data. A generic face template can be considered as a 3D filter that rejects noise in the range map data. Generic face templates will be understood by those skilled in the art.

Step 306 uses the range map data to derive or compute a 3D surface. Any suitable algorithm can be used and will be apparent to those skilled in the art. Exemplary algorithms are described in the following papers: Turk & Levoy,

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algorithm) will not precisely correspond because of errors in placement. Second, head shape and size varies from person to person.

The first mismatch can be overcome by resampling the motion capture displacement data for all faces at a fixed set of positions on a generic mesh. This is described below in more detail in the section entitled “Exemplary System and Method for Building a Face Model.” There, the fixed set of positions is referred to as the “standard sample positions”. The resampling function is the mesh deformation function. The standard sample positions are the vertices of the face mesh that correspond to the vertices of the generic mesh subdivided once.

The second mismatch requires transforming displacement data from one face to another to compensate for changes in size and shape of the face. In the illustrated example, this is done by finding a small training set of corresponding expressions for the two data sets and then finding the best linear transformation from one to another. As an example, consider the following: In an experimental environment, emotion expressions were manually labeled for 49 corresponding expressions including various intensities of several expressions. For speech motion, 10,000 frames were automatically aligned using time warping techniques.

Each expression is represented by a $3m$ -vector g that contains all of the x , y , and z displacements at the m standard sample positions. Given a set of n expression vectors for the face to be transformed, $g_{a1...n}$, and a corresponding set of vectors for the target face, $g_{b1...n}$, a set of linear predictors a_j is computed, one for each coordinate of g_a , by solving $3m$ linear least squares systems:

$$a_j \cdot g_{ai} = g_{bi}[j], i = 1..n$$

Exemplary Application

Fig. 6 shows a system 600 that illustrates but one example of how the expression transformation process described above can be employed. System 600 includes a transmitter computing system or transmitter 602 and a receiver computing system or receiver 604 connected for communication by a network 603 such as the Internet. Transmitter 602 includes an illumination system 200 (Fig. 2) that is configured to capture the expressions of a person as described in connection with Fig. 2. Transmitter 602 also includes a code book 400, such as the one described in connection with Fig. 4. It is assumed that the code book has been synthesized into a synthetic set of expressions as described above. That is, using a training set of expressions provided by the person whose expressions illumination system 200 is configured to capture, the code book has been processed to provide the synthesized set of expressions.

Receiver 604 includes a reconstruction module 606 that is configured to reconstruct facial images from data that is received from transmitter 602. Receiver 604 also includes a code book 400 that is identical to the code book that is included with the transmitter 602. Assume now, that the person located at transmitter 602 attempts to communicate with a person located at receiver 604. As the person located at the transmitter 602 moves their face to communicate, their facial expressions and movement are captured and processed by the transmitter 602. This processing can include capturing their expressions and searching the synthesized code book to find the nearest matching expression in the code book. When a matching expression is found in the synthesized code book, an index of

1 that expression can be transmitted to receiver 604 and an animated face can be
2 reconstructed using the reconstruction module 606.

4 **Exemplary Facial Transformation**

5 Fig. 7 shows some effects of expression transfer in accordance with the
6 described embodiment. The pictures in the first row constitute a synthetic face of
7 a first person (person A) that shows three different expressions. These pictures are
8 the result of the captured facial motion of person A. Face motion for a second
9 person (person B) was captured. The captured face motion for person B is shown
10 in the third row. Here, the 3D motion data was captured by placing a number of
11 colored dots on the person's face and measuring the dots' movements when the
12 person's face was deformed, as will be understood by those of skill in the art.
13 Motion data can, however, be captured by the systems and methods described
14 above. Person B's captured motions were then used, as described above, to
15 transform the expressions of person A. The result of this operation is shown in the
16 second row. The expressions in the three sets of pictures all correspond with one
17 another. Notice how the expressions in the first and second row look very similar
18 even though they were derived from two very different people, while the original
19 expressions of the second person (row 3) look totally unlike those of the first and
20 second rows.

22 **Exemplary System and Methods for Building a Face Model**

23 The model of a face that is needed to produce a realistic image has two
24 parts to it. The first part of the model relates to the geometry of the face (i.e. the
25 shape of the surface of the face) while the second part of the model relates to the

1 reflectance of the face (i.e. the color and reflective properties of the face). This
2 section deals with the first part of that model—the geometry of the face.

3 The geometry of the face consists of a skin surface plus additional surfaces
4 for the eyes. In the present example, the skin surface is derived from a laser range
5 scan of the head and is represented by a subdivision surface with displacement
6 maps. The eyes are a separate model that is aligned and merged with the skin
7 surface to produce a complete face model suitable for high quality rendering.

8 9 **Mesh Fitting**

10 The first step in building a face model is to create a subdivision surface that
11 closely approximates the geometry measured by the laser range scanner. In the
12 illustrated example, the subdivision surfaces are defined from a coarse triangle
13 mesh using Loop's subdivision rules. Loop's subdivision rules are described in
14 detail in Charles Loop, *Smooth Subdivision Surfaces Based on Triangles*, PhD
15 thesis, University of Utah, August 1987. In addition, the subdivision surfaces are
16 defined with the addition of sharp edges similar to those described by Hoppe et al.,
17 *Piecewise smooth surface reconstruction*, Computer Graphics (SIGGRAPH '94
18 Proceedings) pps. 295-302, July 1994. Note that the non-regular crease masks are
19 not used. In addition, when subdividing an edge between a dart and a crease
20 vertex, only the new edge adjacent the crease vertex is marked as a sharp edge.

21 A single base mesh is used to define the subdivision surfaces for all of the
22 face models, with only the vertex positions varying to adapt to the shape of each
23 different face. In the illustrated example, a base mesh having 227 vertices and 416
24 triangles was defined to have the general shape of a face and to provide greater
25 detail near the eyes and lips, where the most complex geometry and motion occur.

1 The mouth opening is a boundary of the mesh, and is kept closed during the fitting
2 process by tying together the positions of the corresponding vertices on the upper
3 and lower lips. The base mesh has a few edges marked for sharp subdivision rules
4 that serve to create corners at the two sides of the mouth opening and to provide a
5 place for the sides of the nose to fold. Because the modified subdivision rules
6 only introduce creases for chains of at least three sharp edges, this model does not
7 have creases in the surface; only isolated vertices fail to have well-defined limit
8 normals.

9 Fig. 8 shows an example of a coarse defined mesh (the center figure) that
10 was used in accordance with this example. Fig. 8 visually shows how the coarse
11 mesh can be used to map the same subdivision control (coarse) mesh to a
12 displaced subdivision surface for each face so that the result is a natural
13 correspondence from one face to another. This aspect is discussed in more detail
14 below.

15 The process used to fit the subdivision surface to each face is based on an
16 algorithm described by Hoppe et al. *Piecewise smooth surface reconstruction*,
17 Computer Graphics (SIGGRAPH '94 Proceedings) pps. 295-302, July 1994.
18 Hoppe's surface fitting method can essentially be described as consisting of three
19 phases: a topological type estimation (phase 1), a mesh optimization (phase 2), and
20 a piecewise smooth surface optimization (phase 3).

21 Phase 1 constructs a triangular mesh consisting of a relatively large number
22 of triangles given an unorganized set of points on or near some unknown surface.
23 This phase determines the topological type of the surface and produces an initial
24 estimate of geometry. Phase 2 starts with the output of phase 1 and reduces the
25 number of triangles and improves the fit to the data. The approach is to cast the

problem as optimization of an energy function that explicitly models the trade-off between the competing goals of concise representation and good fit. The free variables in the optimization procedure are the number of vertices in the mesh, their connectivity, and their positions. Phase 3 starts with the optimized mesh (a piecewise linear surface) that is produced in phase 2 and fits an accurate, concise piecewise smooth subdivision surface, again by optimizing an energy function that trades off conciseness and fit to the data. The phase 3 optimization varies the number of vertices in the control mesh, their connectivity, their positions, and the number and locations of sharp features. The automatic detection and recovery of sharp features in the surface is an essential part of this phase.

In the present embodiment, processing differs from the approach described in Hoppe et al. in a couple of ways. First, continuous optimization is performed only over vertex positions, since we do not want to alter the connectivity of the control mesh. Additionally, feature constraints are added as well as a smoothing term.

In the illustrated example, the fitting process minimizes the functional:

$$E(\mathbf{v}) = E_d(\mathbf{v}, \mathbf{p}) + \lambda E_s(\mathbf{v}) + \mu E_c(\mathbf{v})$$

where \mathbf{v} is a vector of all the vertex positions, and \mathbf{p} is a vector of all the data points from the range scanner. The subscripts on the three terms stand for distance, shape, and constraints. The distance functional E_d measures the sum-squared distance from the range scanner points to the subdivision surface:

$$E_d(\mathbf{v}, \mathbf{p}) = \sum_{i=1}^{n_p} a_i \|p_i - \Pi(\mathbf{v}, p_i)\|^2$$

Fig. 10 is a flow diagram that describes steps in a method for building a face model in accordance with this described embodiment. The method can be implemented in any suitable hardware, software, firmware or combination thereof. In the present example, the method is implemented in software.

Step 1000 measures 3D data for one or more faces to provide corresponding face models. In the above example, the 3D data was generated through the use of a laser range scan of the faces. It will be appreciated that any suitable method of providing the 3D data can be used. Step 1002 defines a generic face model that is to be used to fit to the one or more face models. It will be appreciated that the generic face model can advantageously be utilized to fit to many different faces. Accordingly, this constitutes an improvement over past methods in which this was not done. In the example described above, the generic face model comprises a mesh structure in the form of a coarse triangle mesh. The triangle mesh defines subdivision surfaces that closely approximate the geometry of the face. In the illustrated example, a single base mesh is used to define the subdivision surfaces for all of the face models. Step 1004 selects specific points or constraints on the generic face model. These specific points or constraints are

mapped directly to corresponding points that are marked on the face model. The mapping of these specific points takes place in the same manner for each of the many different possible face models. Step 1006 fits the generic face model to the one or more face models. This step is implemented by manipulating only the positions of the vertices to adapt to the shape of each different face. During the fitting process continuous optimization is performed only over the vertex positions so that the connectivity of the mesh is not altered. In addition, the fitting process involves mapping the specific points or constraints directly to the face model. In addition, a smoothing term is added and minimized so that the control mesh is encouraged to be locally planar.

Adding Eyes

The displaced subdivision surface just described represents the shape of the facial skin surface quite well. There are, however, several other features that are desirable for a realistic face. The most important of these is the eyes. Since the laser range scanner does not capture suitable information about the eyes, the mesh is augmented for rendering by adding separately modeled eyes. Unlike the rest of the face model, the eyes and their motions are not measured from a specific person, so they do not necessarily reproduce the appearance of the real eyes. However, their presence and motion is critical to the overall appearance of the face model.

Any suitable eye model can be used to model the eyes. In the illustrated example, a commercial modeling package was used to build a model consisting of two parts. The first part is a model of the eyeball, and the second part is a model of the skin surface around the eye, including the eyelids, orbit, and a portion of the

surrounding face (this second part will be called the “orbit surface”). In order for the eye to become part of the overall face model, the orbit surface must be made to fit the individual face being modeled and the two surfaces must be stitched together. This is done in two steps: first the two meshes are warped according to a weighting function defined on the orbit surface, so that the face and orbit are coincident where they overlap. Then the two surfaces are cut with a pair of concentric ellipsoids and stitched together into a single mesh.

Note that one of the advantageous features of the embodiments described above is that they provide a structure or framework that can be used to transform the expressions of one person into expressions of another person. Because the fit of the generic face model to each individual face is constrained so that any given part of the generic model always maps to the same feature on every person's face—for example, the left corner of the mouth in the generic model always maps to the left corner of the mouth on any person's face—the set of fitted face models provides a means for determining the point on any face that corresponds to a particular point on a particular face. For example, suppose the motion of the left corner of the mouth on person A's face has been measured. We can use the fit of the generic model to face A to determine which point of the generic model corresponds to that measured point, and then we can use the fit of the generic model to face B to determine which point on B's face corresponds to the computed point on the generic model and therefore also to the measured point on face A. This information is essential to transforming motion from one face to another because we have to know which parts of the new face need to be moved to reproduce the motions we measured from a set of points on the measured face.

Moving the Face

The motions of the face are specified by the time-varying 3D positions of a set of sample points on the face surface. When the face is controlled by motion-capture data these points are the markers on the face that are tracked by the motion capture system. The motions of these points are used to control the face surface by way of a set of control points that smoothly influence regions of the surface. Capturing facial motion data can be done in any suitable way, as will be apparent to those of skill in the art. In one specific example, facial motion was captured using the technique described in Guenter et al., *Making Faces*, Proceedings of SIGGRAPH 1998, pages 55-67, 1998.

Mesh Deformation

The face is animated by displacing each vertex w_i of the triangle mesh from its rest position according to a linear combination of the displacements of a set of control points q_j . These control points correspond one-to-one with the sample points p_j that describe the motion. The influence of each control point on the vertices falls off with distance from the corresponding sample point, and where multiple control points influence a vertex, their weights are normalized to sum to 1.

$$\Delta w_i = \frac{1}{\beta_i} \sum_j \alpha_{ij} \Delta q_j \quad ; \alpha_{ij} = h(\|w_i - p_j\| / r)$$

where $\beta_i = \sum_k \alpha_{ik}$ if vertex i is influenced by multiple control points and 1 otherwise. These weights are computed once, using the rest positions of the sample points and face mesh, so that moving the mesh for each frame is just a

1 rotating the vertices that define them about an axis through the center of the
2 eyeball, using weights defined on the eyelid mesh to ensure smooth deformations.

3 The rigid-body motion of the head is captured from the physical motion of
4 a person's head by filming that motion while the person is wearing a hat marked
5 with special machine-recognizable targets (the hat is patterned closely on the one
6 used by Marschner et al., *Image-based BRDF measurement including human skin*,
7 *Rendering Techniques '99* (Proceedings of the Eurographics Workshop on
8 *Rendering*), pps. 131-144, June 1998. By tracking these targets in the video
9 sequence, the rigid motion of the head is computed, which is then applied to the
10 head model for rendering. This setup, which requires simply a video camera,
11 provides a convenient way to author head motion by demonstrating the desired
12 actions.

13 14 **Exemplary System and Methods for Modeling Reflectance**

15 Rendering a realistic image of a face requires not just accurate geometry,
16 but also accurate computation of light reflection from the skin. In the illustrated
17 example, a physically-based Monte Carlo ray tracer was used to render the face.
18 Exemplary techniques are described in Cook et al., *Distribution Ray Tracing*,
19 *Computer Graphics (SIGGRAPH '84 Proceedings)*, pps. 165-174, July 1984 and
20 Shirley et al., *Monte Carlo techniques for direct lighting calculations*,
21 *Transactions on Graphics*, 15(1):1-36, 1996. Doing so allows for the use of
22 arbitrary BRDFs (bi-directional reflectance distribution functions) to correctly
23 simulate the appearance of the skin, which is not well approximated by simple
24 shading models. In addition, extended light sources are used, which, in rendering
25 as in portrait photography, are needed to achieve a pleasing image. Two important

1 *reflectance functions*, Computer Graphics (SIGGRAPH '97 Proceedings), pps.
2 117-126, August 1997.

3 4 **Constructing the Albedo Map**

5 In the illustrated and described embodiment, the albedo map, which must
6 describe the spatially varying reflectance due to diffuse reflection, was measured
7 using a sequence of digital photographs of the face taken under controlled
8 illumination.

9 Fig. 11 shows an exemplary system that was utilized to capture the digital
10 photographs or images. In the illustrated system, a digital camera 1100 is
11 provided and includes multiple light sources, exemplary ones of which are shown
12 at 1102, 1104. Polarizing filters in the form of perpendicular polarizers 1106,
13 1108, and 1110 are provided and cover the light sources and the camera lens so
14 that the specular reflections are suppressed, thereby leaving only the diffuse
15 component in the images. In the example, a subject wears a hat 1112 printed with
16 machine-recognizable targets to track head pose. Camera 1100 stays stationary
17 while the subject rotates. The only illumination comes from the light sources
18 1102, 1104 at measured locations near the camera. A black backdrop is used to
19 reduce indirect reflections from spilled light.

20 Since the camera and light source locations are known, standard ray tracing
21 techniques can be used to compute the surface normal, the irradiance, the viewing
22 direction, and the corresponding coordinates in texture space for each pixel in each
23 image. Under the assumption that ideal Lambertian reflection is being observed,
24 the Lambertian reflectance can be computed for a particular point in texture space
25 from this information. This computation is repeated for every pixel in one

1 occluded pixels and pixels that are in full-shadow or penumbra regions are not
2 used.

3 Some calibration is required to make these measurements meaningful. The
4 camera's transfer curve was calibrated using the method described in Debevec et
5 al., *Recovering high dynamic range radiance maps from photographs*, Computer
6 Graphics (SIGGRAPH '97 Proceedings), pps. 369-378, August 1997. The
7 light/camera system's flat-field response was calibrated using a photograph of a
8 large white card. The lens's focal length and distortion were calibrated using the
9 technique described in Zhang, *A flexible new technique for camera calibration*,
10 Technical Report MSR-TR-98-71, Microsoft Research, 1998. The absolute scale
11 factor was set using a reference sample of known reflectance. When image-to-
12 image variation in light source intensity was a consideration, control was provided
13 by including the reference sample in every image.

14 The texture maps that result from this process do a good job of
15 automatically capturing the detailed variation in color across the face. In a few
16 areas, however, the system cannot compute a reasonable result. Additionally, the
17 strap used to hold the calibration hat in place is visible. These problems are
18 removed by using an image editing tool and filling in blank areas with nearby
19 texture or with uniform color.

20 Figs. 14 and 15 show the raw and edited albedo maps for comparison. The
21 areas where the albedo map does not provide reasonable results can be seen where
22 the surface is not observed well enough (e. g., under the chin) or is too intricately
23 shaped to be correctly scanned and registered with the images (e.g the ears).
24 Neither of these types of areas requires the texture from the albedo map for
25 realistic appearance—the first because they are not prominently visible and the

second because the geometry provides visual detail—so this editing has relatively little effect on the appearance of the final renderings.

Fig. 16 shows several different aspects of the face model, using still frames from the accompanying video. In the first row, the face is shown from several angles to demonstrate that the albedo map and measured BRDF realistically capture the distinctive appearance of the skin and its color variation over the entire face, viewed from any angle. The second row shows the effects of rim and side lighting, including strong specular reflections at grazing angles. Note that the light source has the same intensity and is at the same distance from the face for all three images in this row. The directional variation in the reflectance leads to the familiar lighting effects seen in the renderings. In the third row, expression deformations are applied to the face to demonstrate that the face still looks natural under normal expression movement.

Fig. 17 is a flow diagram that describes steps in a method for creating an albedo map in accordance with the described embodiment. The method can be implemented in any suitable hardware, software, firmware or combination thereof. In the described embodiment, the method is implemented in software in connection with a system such as the one shown and described in Fig. 11.

Step 1700 provides one or more polarized light sources that can be used to illuminate a subject. Exemplary light sources are described above. In the described embodiment, the light sources are selected so that the specular component of the subject's facial reflectance is suppressed or eliminated. Step 1702 illuminates the subject's face with the light sources. Step 1704 rotates the subject while a series of digital photographs or images are taken. Step 1706 computes surface normals, irradiance, viewing direction and coordinates in texture

1 1808 computes an albedo and a weight for the pixel. The weights are later used in
2 averaging together individual maps. Hence, as discussed above, albedos are
3 computed only for pixels that are fully visible, fully illuminated by at least one
4 light source, and not partially illuminated by any light source. This ensures that
5 partially occluded pixels and pixels that are in full-shadow or penumbra are not
6 used.

7 8 **Conclusion**

9 The embodiments described above provide systems and methods that
10 address the challenge of modeling and rendering faces to the high standard of
11 realism that must be met before an image as familiar as a human face can appear
12 believable. The philosophy of the approach is to use measurements whenever
13 possible so that the face model actually resembles a real face. The geometry of the
14 face is represented by a displacement-mapped subdivision surface that has
15 consistent connectivity and correspondence across different faces. The reflectance
16 comes from previous BRDF measurements of human skin together with new
17 measurements that combine several views into a single illumination-corrected
18 texture map for diffuse reflectance. The motion comes from previously described
19 motion capture technique and is applied to the face model using an improved
20 deformation method that produces motions suitable for shaded surfaces. The
21 realism of the renderings is greatly enhanced by using the geometry, motion, and
22 reflectance of real faces in a physically-based renderer.

23 Although the invention has been described in language specific to structural
24 features and/or methodological steps, it is to be understood that the invention
25 defined in the appended claims is not necessarily limited to the specific features or

1 **CLAIMS**

2 1. A facial expression transformation method comprising:
3 defining a code book containing data defining a first set of facial
4 expressions of a first person;
5 providing data defining a second set of facial expressions, the second set of
6 facial expressions providing a training set of expressions of a second person who
7 is different from the first person;
8 deriving a transformation function from the training set of expressions and
9 corresponding expressions from the first set of expressions; and
10 applying the transformation function to the first set of expressions to
11 provide a synthetic set of expressions.

12
13 2. The method of claim 1, wherein the training set of expressions
14 contains fewer expressions than the code book.

15
16 3. The method of claim 1, wherein the transformation function
17 compensates for differences in the size and shape of the faces of the first and
18 second persons.

19
20 4. The method of claim 1, wherein said deriving of the transformation
21 function comprises computing a linear transformation from one set of expressions
22 to another.
23
24
25

1 5. The method of claim 1, wherein the deriving of the transformation
2 function comprises:

3 representing each expression as a $3m$ -vector that contains x , y , z
4 displacements at m standard sample positions; and

5 computing a set of linear predictors a_j , one for each coordinate of g_a , given
6 a set of n expression vectors for a face to be transformed, $g_{a1...n}$, and a
7 corresponding set of vectors for a target face, $g_{b1...n}$, by solving $3m$ linear least
8 squares systems of the following form:

$$a_j \cdot g_a = g_b[j], i = 1...n$$

9
10
11 6. The method of claim 5, wherein said computing comprises using only
12 a subset of points for each g_{aj} .

13
14 7. The method of claim 6, wherein said using comprises using only
15 points that share edges with a standard sample point under consideration.

16
17 8. The method of claim 5 further comprising controlling the spread of
18 singular values when computing a pseudoinverse to solve for the a_j .

19
20 9. The method of claim 8, wherein said controlling the spread comprises
21 zeroing out all singular values less than $\alpha\sigma_1$, where σ_1 is the largest singular value
22 of the matrix.
23
24
25

1 **10.** The method of claim 1, wherein said providing data defining a
2 second set of facial expressions comprises:

3 illuminating the second person's face with illumination; and
4 contemporaneously capturing structure data describing the face's structure
5 and reflectance data describing reflectance properties of the face from the
6 illumination.

7
8 **11.** The method of claim 10, wherein said illuminating comprises:
9 using multiple light sources, one of which projecting a pattern on the
10 second person's face from which the structure data can be ascertained;

11 at least one of the light sources comprising an infrared light source;
12 at least one of the light sources being polarized; and
13 said capturing comprising using a camera having a polarizer that suppresses
14 specularly-reflected light so that diffuse component reflection data is captured.

15
16 **12.** The method of claim 1, wherein said providing data defining a
17 second set of facial expressions comprises:

18 illuminating the second person's face with a first polarized light source that
19 is selected so that specularly-suppressed reflective properties of the face can be
20 ascertained;

21 illuminating the second person's face with a second structured light source
22 that projects a pattern onto the face, while simultaneously illuminating the face
23 with the first polarized light source; and

24 capturing both specularly-suppressed reflection data and structure data from
25 the simultaneous illumination.

1
2 **13.** The method of claim 12, wherein the light sources provide light at
3 different frequencies.

4
5 **14.** The method of claim 12, wherein the light sources provide infrared
6 light.

7
8 **15.** The method of claim 12, further comprising processing the captured
9 data to provide both (a) data that describes dimensional aspects of the face and (b)
10 data that describes diffuse reflective properties of the face.

11
12 **16.** The method of claim 1, wherein said providing data defining a
13 second set of facial expressions comprises:

14 illuminating the second person's face with multiple different light sources;
15 measuring range map data from said illuminating;
16 measuring image data from said illuminating;
17 deriving a 3-dimensional surface from the range map data;
18 computing surface normals to the 3-dimensional surface; and
19 processing the surface normals and the image data to derive an albedo map.

20
21 **17.** The method of claim 16, wherein at least one of the light sources is
22 polarized.

1 **18.** The method of claim 16, wherein all of the light sources are
2 polarized.

3
4 **19.** One or more computer-readable media having computer-readable
5 instructions thereon which, when executed by a computer, cause the computer to:

6 operate on a training set of expressions from one person and corresponding
7 expressions from a code book of another person to compute a linear
8 transformation function from the training set and their corresponding expressions;
9 and

10 apply the transformation function to a plurality of expressions from the
11 code book to provide a synthetic set of expressions.

12
13 **20.** The computer-readable media of claim 19, wherein the instructions
14 cause the computer to use the synthetic set of expressions to transform expressions
15 from the one person into expressions of the other person.

16
17 **21.** The computer-readable media of claim 20, wherein the instructions
18 cause the computer to transform expressions from the one person that are different
19 from those expressions comprising the code book expressions.

20
21 **22.** The computer-readable media of claim 20, wherein the instructions
22 cause the computer to transform expressions by transmitting at least one index of a
23 synthetic expression to a receiver that can reconstruct the expression.

1 **23.** The computer-readable media of claim 20, wherein the instructions
2 cause the computer to transform facial expressions.

3
4 **24.** A facial expression transformation system comprising:
5 a code book embodied on a computer-readable medium, the code book
6 containing data defining a first set of facial expressions of a first person;
7 data embodied on a computer-readable medium, the data defining a second
8 set of facial expressions, the second set of facial expressions providing a training
9 set of expressions of a second person who is different from the first person; and
10 a transformation processor configured to derive a transformation function
11 from the training set of expressions and corresponding expressions from the first
12 set of expressions.

13
14 **25.** The expression transformation system of claim 24, wherein the
15 transformation processor comprises a linear transformation processor.

16
17 **26.** The expression transformation system of claim 24 further
18 comprising a synthetic set of expressions embodied on a computer-readable
19 medium, the synthetic set of expressions being derived by applying the
20 transformation function to the code book expressions.

21
22 **27.** The expression transformation system of claim 24, wherein the
23 transformation function compensates for differences in the size and shape of the
24 faces of the first and second persons.
25

1 **28.** The expression transformation system of claim 24, wherein the
2 transformation processor derives the transformation function by:

3 representing each expression as a $3m$ -vector that contains x , y , z
4 displacements at m standard sample positions; and

5 computing a set of linear predictors a_j , one for each coordinate of g_a , given
6 a set of n expression vectors for a face to be transformed, $g_{a1...n}$, and a
7 corresponding set of vectors for a target face, $g_{b1...n}$, by solving $3m$ linear least
8 squares systems of the following form:

$$a_j \cdot g_{a_i} = g_{b_i}[j], i = 1...n$$

11 **29.** A facial expression transformation system comprising:

12 a transmitter comprising:

13 a facial illumination system that is configured to provide multiple
14 different light sources at the same time for illuminating a subject's face;

15 a data-capturing system configured to capture both structure data and
16 reflectance data from the subject's face when illuminated by the facial
17 illumination system; and

1 a first code book of synthetic expressions that have been synthesized
2 by:

3 receiving a training set of expressions provided by the
4 subject;

5 computing a transformation function using the training set of
6 expressions and corresponding unsynthesized code book
7 expressions; and

8 applying the transformation function to all of the expressions
9 in the code book; and

10 a receiver communicatively linked with the transmitter and comprising:

11 a reconstruction module for reconstructing facial images; and

12 a second code book containing the same synthetic expressions as the
13 first code book; and

14 the transmitter being configured to:

15 capture additional expressions of the subject;

16 search the first code book for a corresponding or near
17 matching expression; and

18 transmit an index of a corresponding or matching code book
19 expression to the receiver for facial image reconstruction by the
20 reconstruction module.

21
22 **30.** The expression transformation system of claim 29, wherein the
23 illumination system comprises at least one polarized light source.
24
25

1 **31.** The expression transformation system of claim 29, wherein the
2 illumination system comprises multiple polarized light sources.

3
4 **32.** The expression transformation system of claim 29, wherein the
5 illumination system comprises a patterned light source configured to project a
6 pattern onto the subject's face.

7
8 **33.** The expression transformation system of claim 29, wherein the
9 illumination system comprises an infrared patterned light source configured to
10 project a pattern onto the subject's face.

11
12 **34.** The expression transformation system of claim 29, wherein the
13 different light sources are all infrared light sources.

14
15 **35.** A method of animating facial features comprising:
16 defining a subdivision surface that approximates geometry of a plurality of
17 different faces; and
18 fitting the same subdivision surface to each of the plurality of faces.

19
20 **36.** The method of claim 35, wherein said defining comprises defining
21 the subdivision surface with a coarse mesh structure.

22
23 **37.** The method of claim 36, wherein the coarse mesh structure
24 comprises a triangular mesh.
25

1 **45.** One or more computer-readable media having computer-readable
2 instructions thereon which, when executed by one or more computers, cause the
3 one or more computers to implement the method of claim 35.

4
5 **46.** A method of animating facial features comprising:
6 defining a subdivision surface that approximates geometry of a plurality of
7 different faces;
8 fitting the same subdivision surface to each of the plurality of faces to
9 establish a correspondence between the faces; and
10 using the correspondence between the faces to transform an expression of
11 one face into an expression of another face.

12
13 **47.** A method of animating facial features comprising:
14 measuring 3-dimensional data for a plurality of different faces to provide
15 corresponding face models;
16 defining only one generic face model that is to be used to map to each
17 corresponding face model;
18 selecting a plurality of points on the generic face model that are to be
19 mapped directly to corresponding points on each of the corresponding face
20 models; and
21 fitting the generic face model to each of the corresponding face models,
22 said fitting comprising mapping each of the selected points directly to the
23 corresponding points on each of the corresponding face models.
24
25

1 **48.** The method of claim 47, wherein:
2 said defining comprises defining a subdivision surface from a base mesh
3 structure, the subdivision surface containing a plurality of vertices and
4 approximating the geometry of the face models; and
5 said fitting comprises manipulating only the positions of the vertices of the
6 subdivision surface.

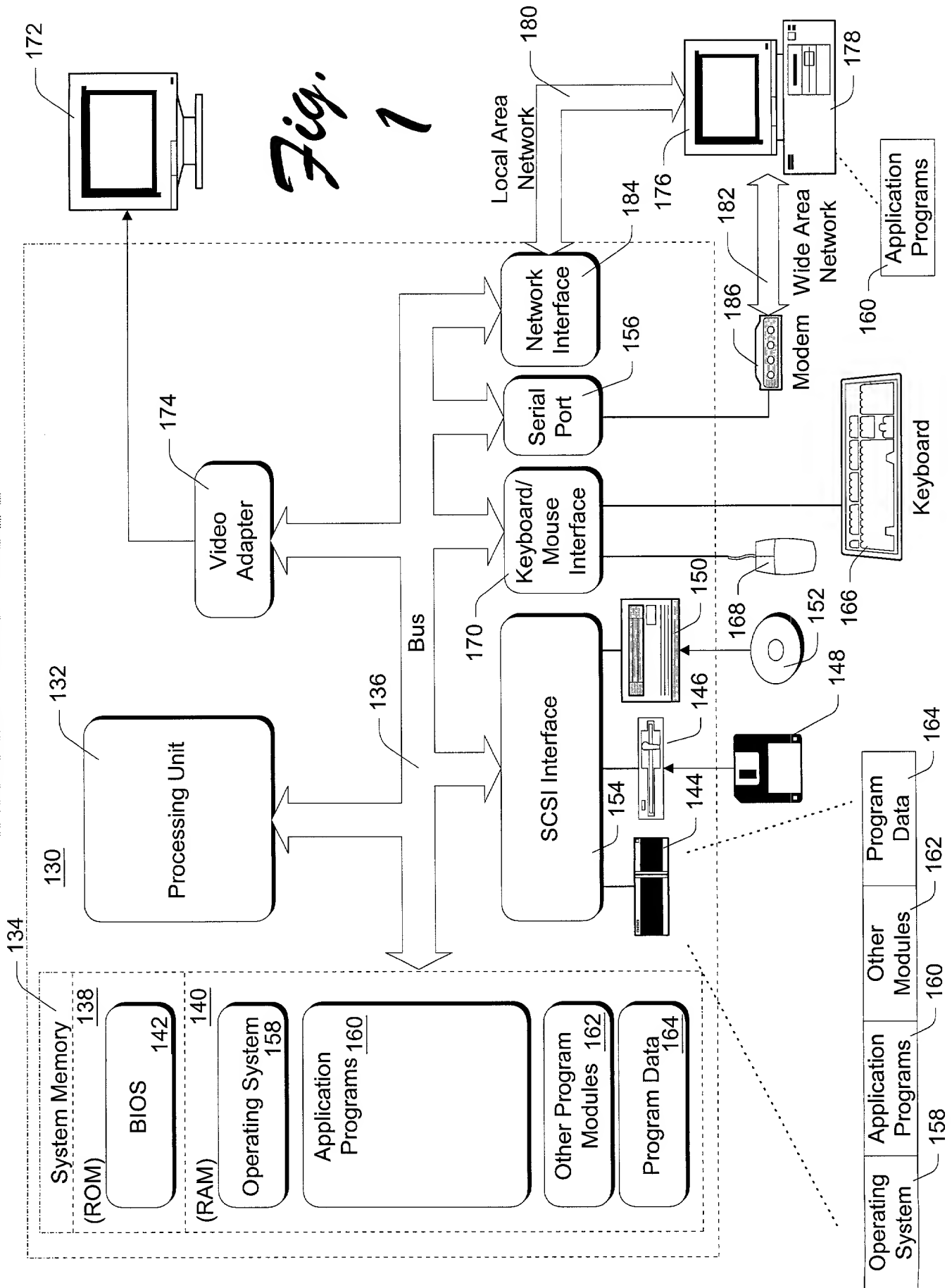
7
8 **49.** The method of claim 47, wherein said fitting comprises
9 manipulating a base mesh that defines a subdivision surface.

10
11 **50.** The method of claim 47, wherein said fitting comprises
12 manipulating a base mesh that defines a subdivision surface without altering the
13 connectivity of the base mesh.

14
15 **51.** The method of claim 47, wherein said measuring comprises using a
16 laser range scan to measure the 3-dimensional data.
17
18
19
20
21
22
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24
25

1 **ABSTRACT**

2 Methods and systems for animating facial features and transforming facial
3 expressions are described. In one embodiment, a code book contains data that
4 defines a set of facial expressions of a first person. A training set of facial
5 expressions from a second person and corresponding expressions from the code
6 book are used to derive a transformation function that is then applied to all of the
7 expressions of the code book. In this manner, expressions from the first person
8 can be realistically transformed into expressions of a second person and vice
9 versa. Particularly advantageous aspects of the described embodiments provide a
10 single common generic face model that is used as the basis for a fitting operation
11 for many different faces. Use of the single common generic face model and
12 certain user-defined constraints provide a mechanism by which correspondences
13 between the different faces can be established. These correspondences provide a
14 basis for facial animation operations, among which are included expression
15 transformation.
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17
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25



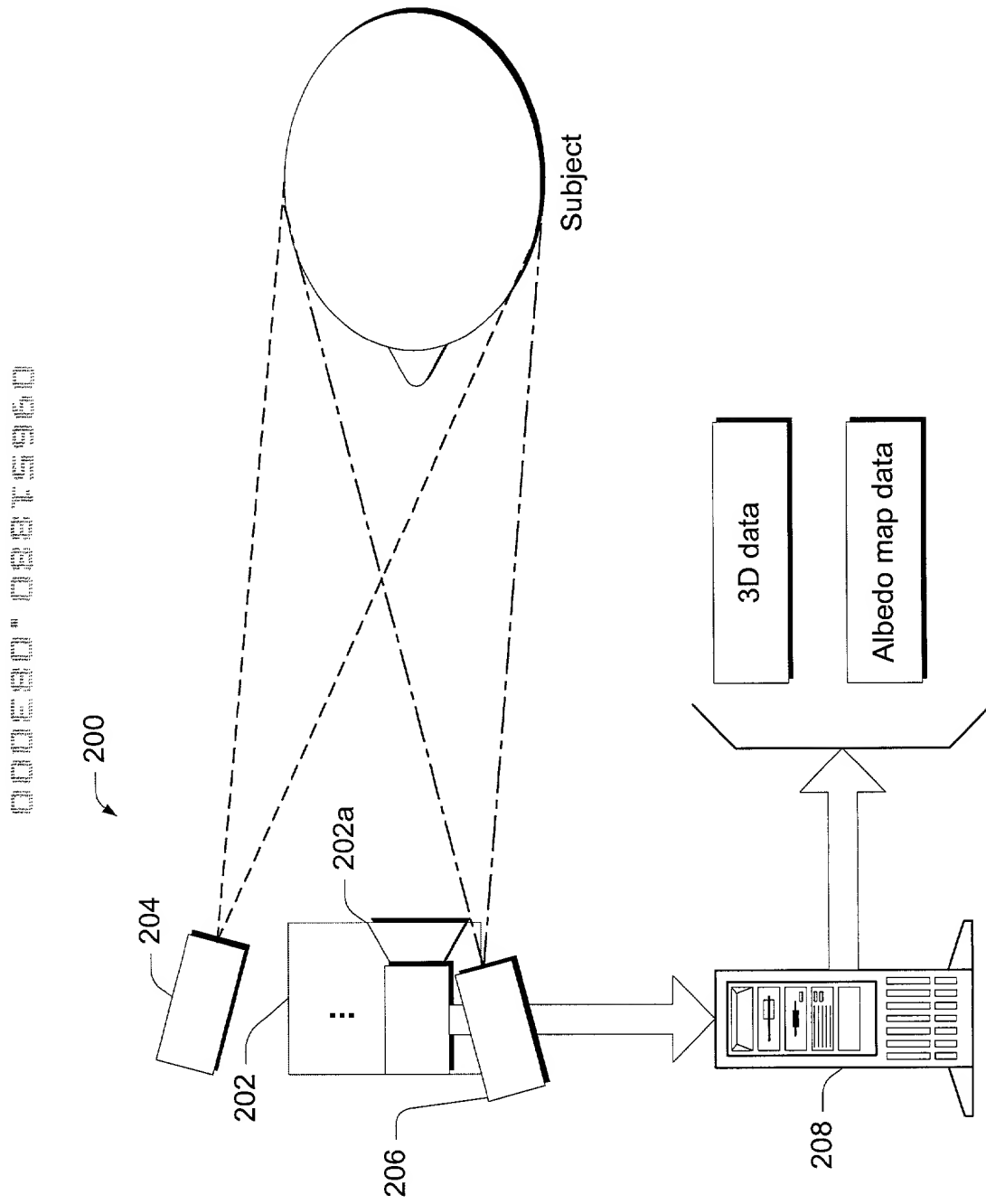


Fig. 2

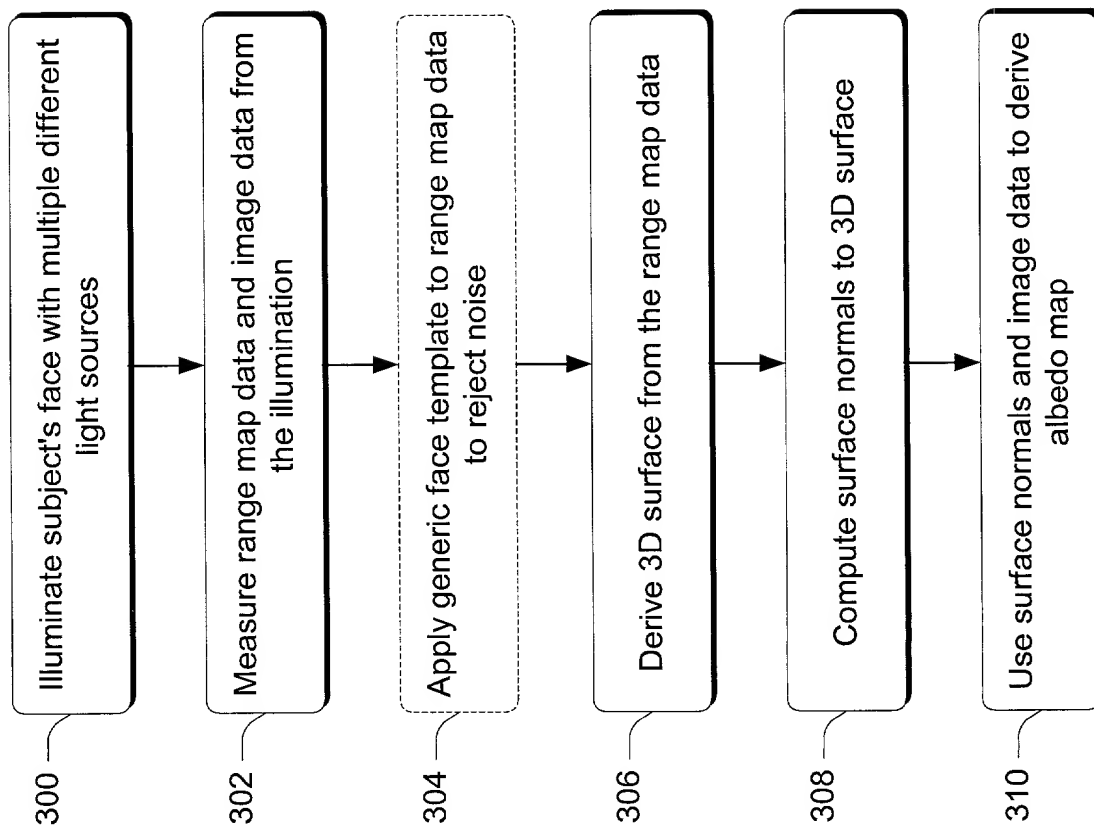


Fig. 3

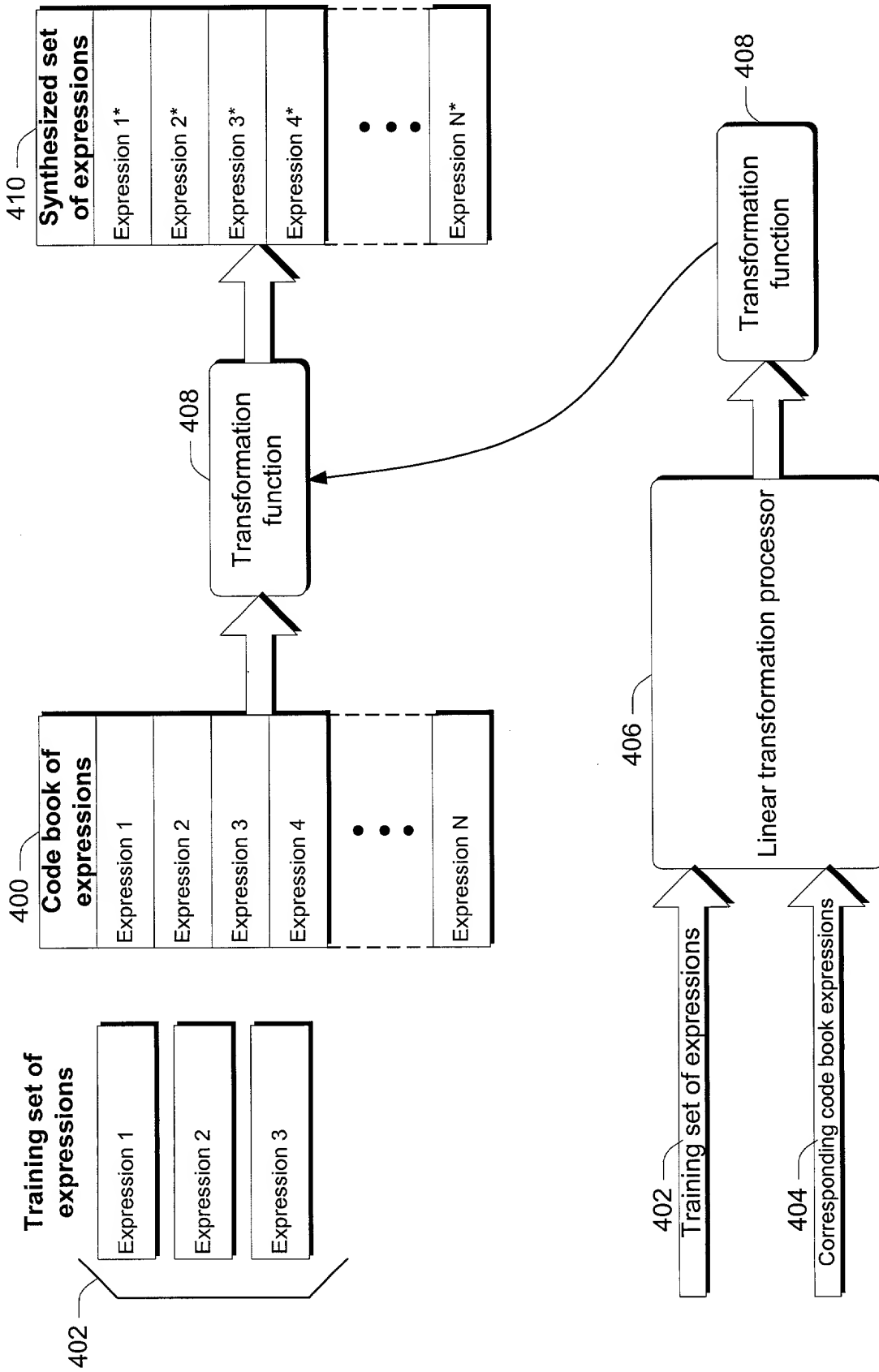


Fig. 4

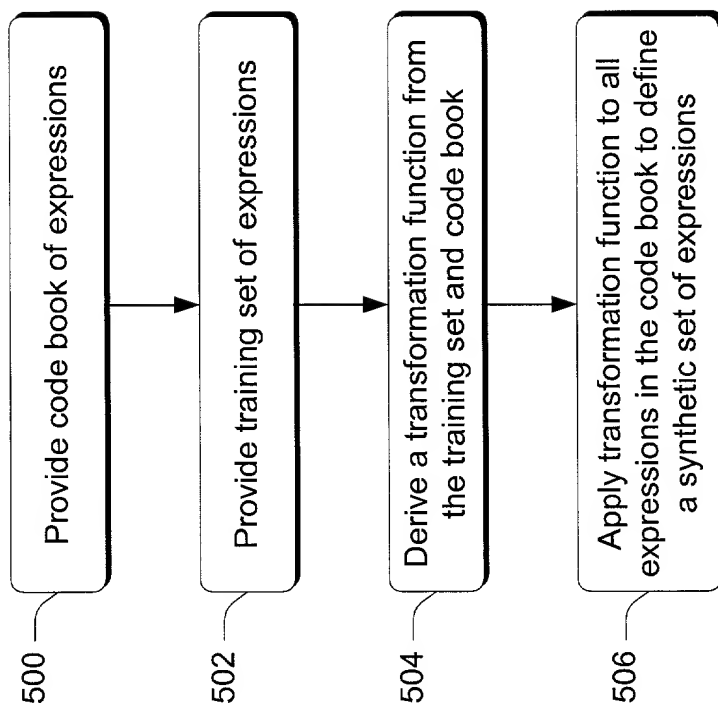


Fig. 5

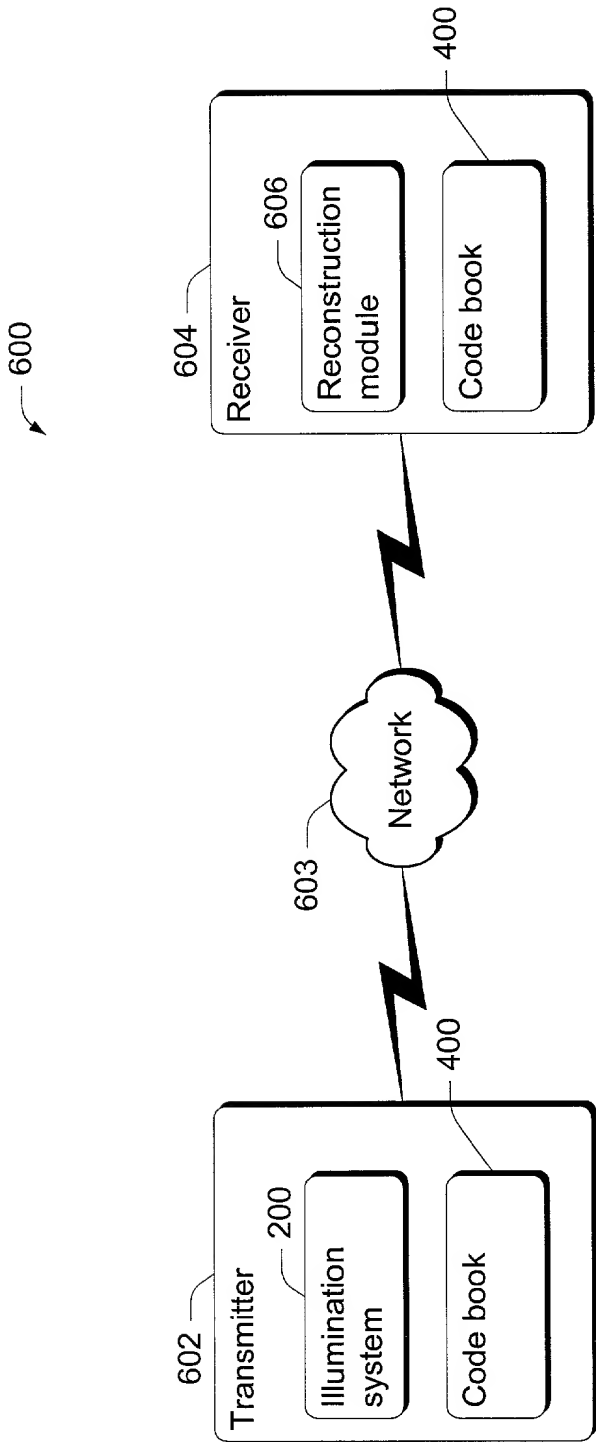


Fig. 6

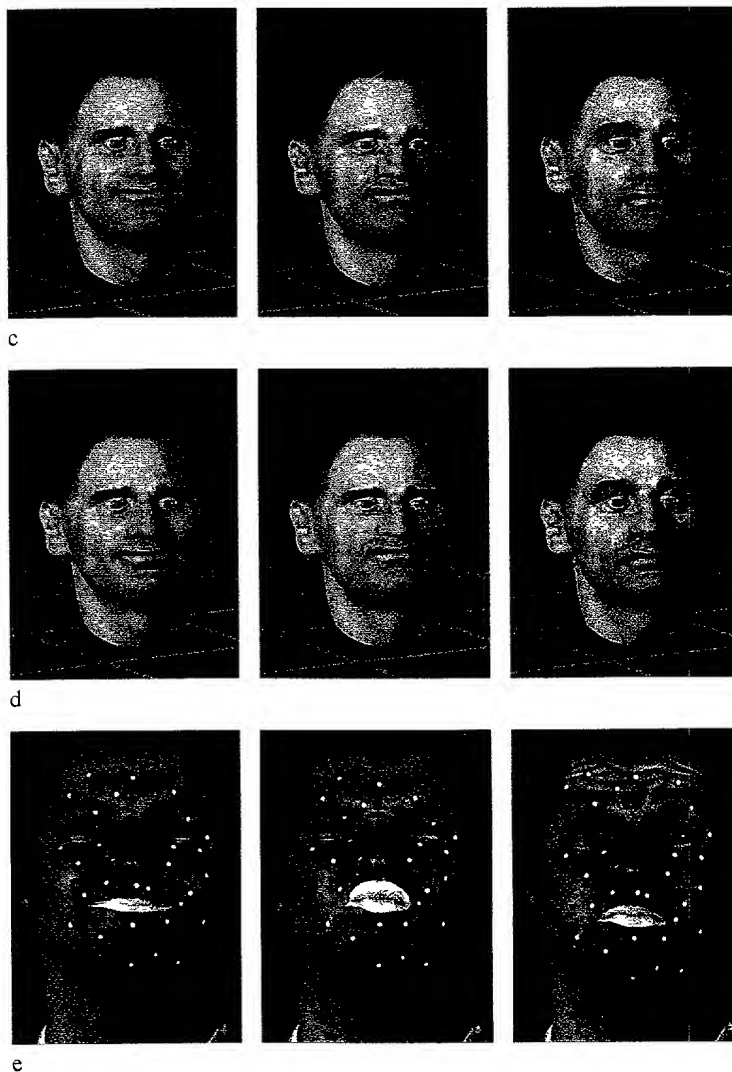


Fig. 7

| Demographics | | Psychiatric History | | Substance Use | | Medical History | | Social History | | Family History | | Mental Status | | Physical Exam | | Laboratory Tests | | Imaging Studies | | Treatment | | Outcome | | | | | | | |
|-----------------|---|---------------------|----------------|----------------|----------|-----------------|------------|----------------|----------------------|----------------|----------|-------------------|------------------------|------------------|--------------|------------------|------------------------|-----------------|-----------------|---------------|--------|------------------|--------|-----------------|--------|-----------|------|---------|--------|
| Age | 35 | Gender | Male | Marital Status | Married | Employment | Unemployed | Education | High School | Religion | Catholic | Current Residence | Apartment | Family Size | 4 | Children | 2 | Parents | 2 | Siblings | 1 | Spouse | 1 | Children | 2 | | | | |
| Current Address | 123 Main St, Apt 4B, New York, NY 10001 | Phone Number | (212) 555-1234 | Insurance | Medicaid | Medication | None | Substance Use | Alcohol (Occasional) | Drugs | None | Medical History | Hypertension, Diabetes | Surgical History | Appendectomy | Family History | Alcoholism, Depression | Mental Status | Alert, Oriented | Physical Exam | Normal | Laboratory Tests | Normal | Imaging Studies | Normal | Treatment | None | Outcome | Stable |

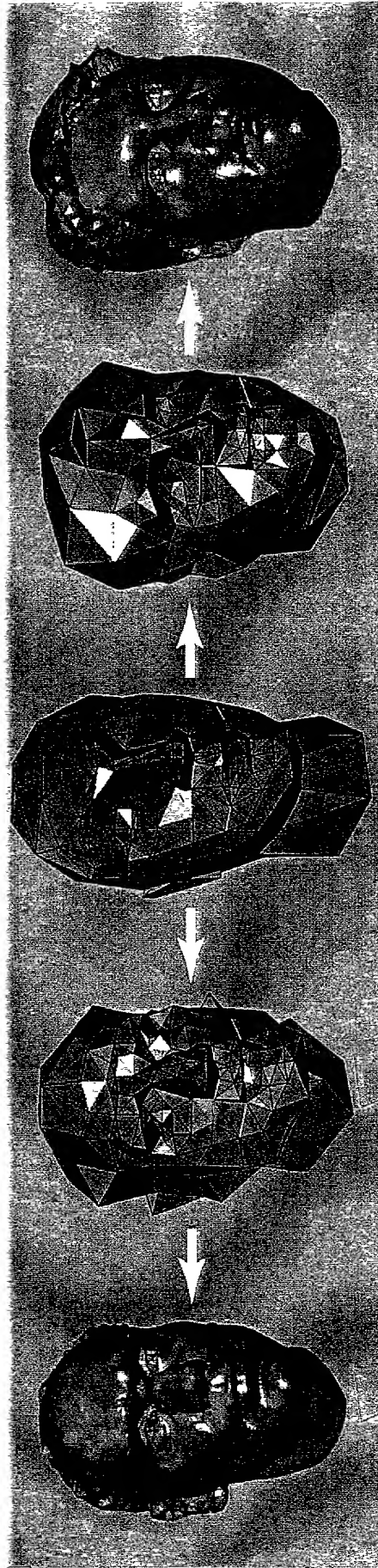
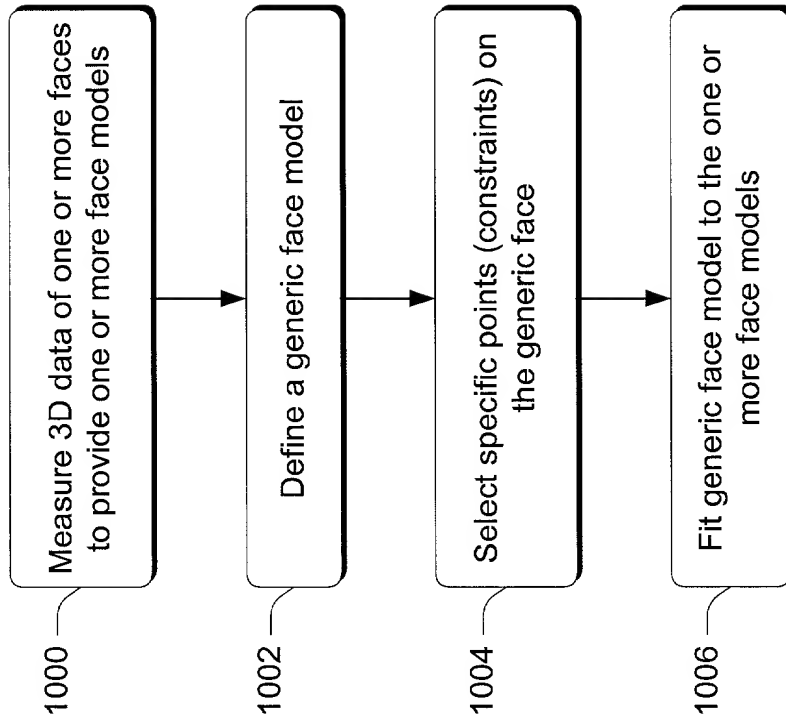


Fig. 8

Figure 1 shows a grayscale image of a human face, labeled 900. A grid of points, also labeled 900, is overlaid on the face, representing a facial landmark detection or tracking system. The points are distributed across the face, with a higher density around the eyes, nose, and mouth.

Fig. 9

DOCKET # 2017-0356

*Fig. 10*

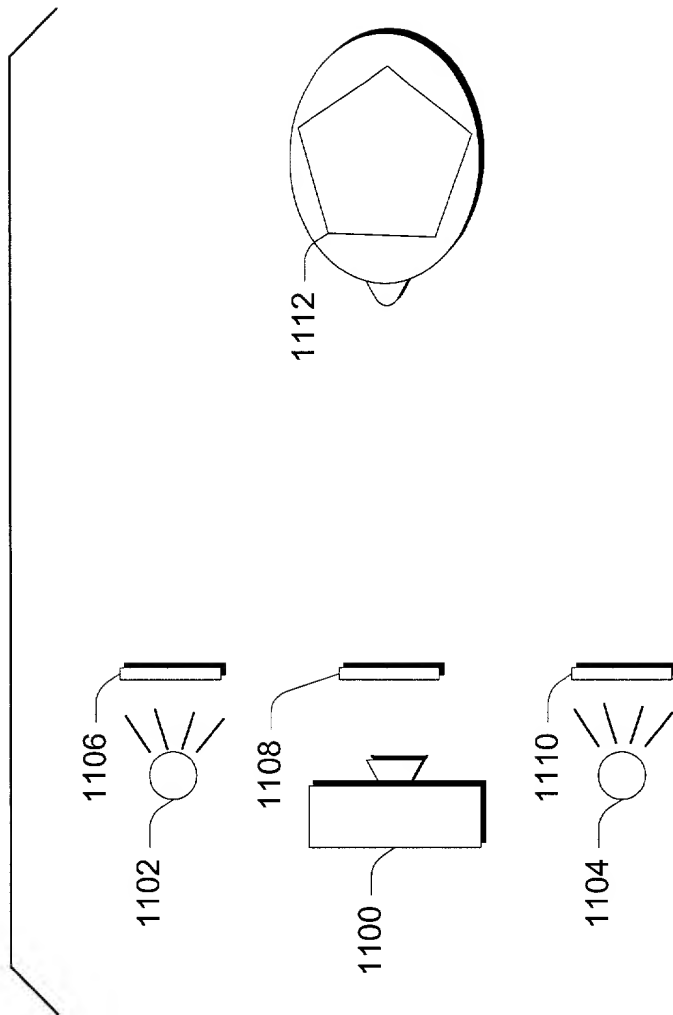


Fig. 11

00000" 08275960



Fig. 12

| Variable | Mean | SD | Min | Max |
|---------------------|------|------|-----|-----|
| Age | 34.5 | 10.2 | 21 | 55 |
| Gender | 1.2 | 0.4 | 1 | 2 |
| Marital Status | 1.5 | 0.5 | 1 | 3 |
| Education | 12.5 | 1.5 | 10 | 16 |
| Income | 15.2 | 3.8 | 10 | 25 |
| Occupation | 1.8 | 0.6 | 1 | 3 |
| Health Status | 1.2 | 0.4 | 1 | 2 |
| Stress Level | 2.5 | 1.2 | 1 | 5 |
| Life Satisfaction | 3.8 | 1.5 | 1 | 6 |
| Resilience | 4.2 | 1.8 | 1 | 7 |
| Optimism | 4.5 | 2.0 | 1 | 7 |
| Emotional Stability | 3.5 | 1.2 | 1 | 6 |
| Self-Esteem | 4.0 | 1.5 | 1 | 7 |
| Life Purpose | 3.2 | 1.0 | 1 | 5 |
| Gratitude | 4.8 | 1.2 | 1 | 7 |
| Forgiveness | 4.5 | 1.5 | 1 | 7 |
| Compassion | 4.2 | 1.8 | 1 | 7 |
| Patience | 4.0 | 1.5 | 1 | 7 |
| Kindness | 4.5 | 1.2 | 1 | 7 |
| Generosity | 4.2 | 1.5 | 1 | 7 |
| Humility | 4.0 | 1.2 | 1 | 7 |
| Modesty | 3.8 | 1.0 | 1 | 6 |
| Meekness | 3.5 | 1.2 | 1 | 6 |
| Lowliness | 3.2 | 1.0 | 1 | 5 |
| Softness | 3.8 | 1.2 | 1 | 6 |
| Gentleness | 4.0 | 1.5 | 1 | 7 |
| Mildness | 3.5 | 1.2 | 1 | 6 |
| Docility | 3.2 | 1.0 | 1 | 5 |
| Submissiveness | 3.0 | 1.2 | 1 | 5 |
| Humility | 3.5 | 1.0 | 1 | 6 |
| Modesty | 3.2 | 1.2 | 1 | 5 |
| Meekness | 3.0 | 1.0 | 1 | 5 |
| Lowliness | 2.8 | 1.2 | 1 | 5 |
| Softness | 3.0 | 1.0 | 1 | 5 |
| Gentleness | 3.2 | 1.2 | 1 | 5 |
| Mildness | 2.8 | 1.0 | 1 | 5 |
| Docility | 2.5 | 1.2 | 1 | 5 |
| Submissiveness | 2.2 | 1.0 | 1 | 5 |
| Humility | 2.8 | 1.2 | 1 | 5 |
| Modesty | 2.5 | 1.0 | 1 | 5 |
| Meekness | 2.2 | 1.2 | 1 | 5 |
| Lowliness | 2.0 | 1.0 | 1 | 5 |
| Softness | 2.2 | 1.2 | 1 | 5 |
| Gentleness | 2.5 | 1.0 | 1 | 5 |
| Mildness | 2.0 | 1.2 | 1 | 5 |
| Docility | 1.8 | 1.0 | 1 | 5 |
| Submissiveness | 1.5 | 1.2 | 1 | 5 |



Fig. 13

000000" 088T5960



Fig. 14

00000" 080T5960

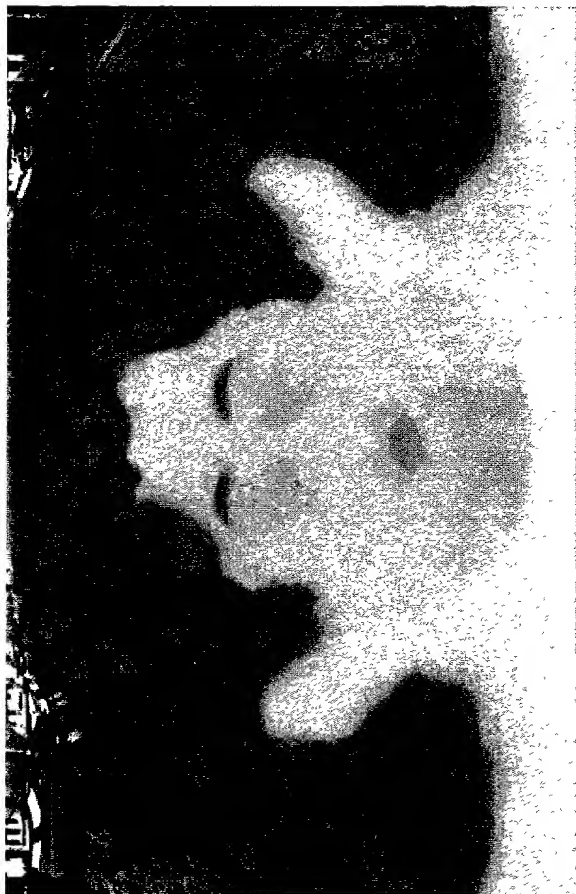


Fig. 15

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 | 2064 | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 2071 | 2072 | 2073 | 2074 | 2075 | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2084 | 2085 | 2086 | 2087 | 2088 | 2089 | 2090 | 2091 | 2092 | 2093 | 2094 | 2095 | 2096 | 2097 | 2098 | 2099 | 2100 | 2101 | 2102 | 2103 | 2104 | 2105 | 2106 | 2107 | 2108 | 2109 | 2110 | 2111 | 2112 | 2113 | 2114 | 2115 | 2116 | 2117 | 2118 | 2119 | 2120 | 2121 | 2122 | 2123 | 2124 | 2125 | 2126 | 2127 | 2128 | 2129 | 2130 | 2131 | 2132 | 2133 | 2134 | 2135 | 2136 | 2137 | 2138 | 2139 | 2140 | 2141 | 2142 | 2143 | 2144 | 2145 | 2146 | 2147 | 2148 | 2149 | 2150 | 2151 | 2152 | 2153 | 2154 | 2155 | 2156 | 2157 | 2158 | 2159 | 2160 | 2161 | 2162 | 2163 | 2164 | 2165 | 2166 | 2167 | 2168 | 2169 | 2170 | 2171 | 2172 | 2173 | 2174 | 2175 | 2176 | 2177 | 2178 | 2179 | 2180 | 2181 | 2182 | 2183 | 2184 | 2185 | 2186 | 2187 | 2188 | 2189 | 2190 | 2191 | 2192 | 2193 | 2194 | 2195 | 2196 | 2197 | 2198 | 2199 | 2200 | 2201 | 2202 | 2203 | 2204 | 2205 | 2206 | 2207 | 2208 | 2209 | 2210 | 2211 | 2212 | 2213 | 2214 | 2215 | 2216 | 2217 | 2218 | 2219 | 2220 | 2221 | 2222 | 2223 | 2224 | 2225 | 2226 | 2227 | 2228 | 2229 | 2230 | 2231 | 2232 | 2233 | 2234 | 2235 | 2236 | 2237 | 2238 | 2239 | 2240 | 2241 | 2242 | 2243 | 2244 | 2245 | 2246 | 2247 | 2248 | 2249 | 2250 | 2251 | 2252 | 2253 | 2254 | 2255 | 2256 | 2257 | 2258 | 2259 | 2260 | 2261 | 2262 | 2263 | 2264 | 2265 | 2266 | 2267 | 2268 | 2269 | 2270 | 2271 | 2272 | 2273 | 2274 | 2275 | 2276 | 2277 | 2278 | 2279 | 2280 | 2281 | 2282 | 2283 | 2284 | 2285 | 2286 | 2287 | 2288 | 2289 | 2290 | 2291 | 2292 | 2293 | 2294 | 2295 | 2296 | 2297 | 2298 | 2299 | 2300 | 2301 | 2302 | 2303 | 2304 | 2305 | 2306 | 2307 | 2308 | 2309 | 2310 | 2311 | 2312 | 2313 | 2314 | 2315 | 2316 | 2317 | 2318 | 2319 | 2320 | 2321 | 2322 | 2323 | 2324 | 2325 | 2326 | 2327 | 2328 | 2329 | 2330 | 2331 | 2332 | 2333 | 2334 | 2335 | 2336 | 2337 | 2338 | 2339 | 2340 | 2341 | 2342 | 2343 | 2344 | 2345 | 2346 | 2347 | 2348 | 2349 | 2350 | 2351 | 2352 | 2353 | 2354 | 2355 | 2356 | 2357 | 2358 | 2359 | 2360 | 2361 | 2362 | 2363 | 2364 | 2365 | 2366 | 2367 | 2368 | 2369 | 2370 | 2371 | 2372 | 2373 | 2374 | 2375 | 2376 | 2377 | 2378 | 2379 | 2380 | 2381 | 2382 | 2383 | 2384 | 2385 | 2386 | 2387 | 2388 | 2389 | 2390 | 2391 | 2392 | 2393 | 2394 | 2395 | 2396 | 2397 | 2398 | 2399 | 2400 | 2401 | 2402 | 2403 | 2404 | 2405 | 2406 | 2407 | 2408 | 2409 | 2410 | 2411 | 2412 | 2413 | 2414 | 2415 | 2416 | 2417 | 2418 | 2419 | 2420 | 2421 | 2422 | 2423 | 2424 | 2425 | 2426 | 2427 | 2428 | 2429 | 2430 | 2431 | 2432 | 2433 | 2434 | 2435 | 2436 | 2437 | 2438 | 2439 | 2440 | 2441 | 2442 | 2 |
|--|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---|
|--|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---|

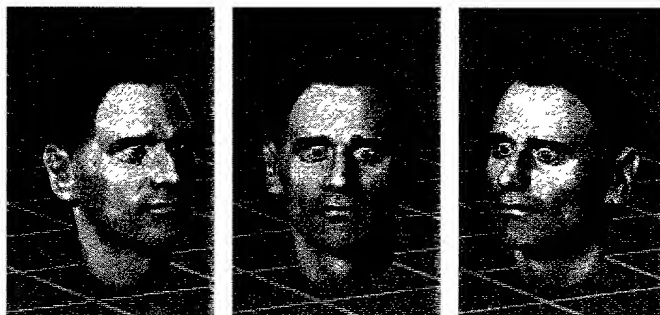


Fig. 16, 1st row

| Climatic data | | Soil data | | Vegetation data | | Water data | | Air data | | Soil data | | Vegetation data | | Water data | | Air data | | | |
|----------------|-----------|------------------|------|--------------------|------------|---------------|------|-----------------|------|---------------|------|--------------------|-----------|---------------|-------|-----------------|------|---------------------|------|
| Variable | Unit | Variable | Unit | Variable | Unit | Variable | Unit | Variable | Unit | Variable | Unit | Variable | Unit | Variable | Unit | Variable | Unit | | |
| Temperature | °C | Soil moisture | % | Vegetation cover | % | Water level | m | Air quality | ppm | Soil pH | pH | Vegetation height | m | Water flow | m³/s | Air humidity | % | | |
| Humidity | % | Soil temperature | °C | Vegetation density | plants/m² | Water quality | ppm | Air temperature | °C | Soil salinity | g/kg | Vegetation biomass | kg/m² | Water pH | pH | Air pressure | hPa | Soil organic matter | % |
| Wind speed | m/s | Soil texture | g/kg | Vegetation species | species/m² | Water flow | m³/s | Air humidity | % | Soil nutrient | g/kg | Vegetation color | RGB | Water level | m | Air quality | ppm | Soil moisture | % |
| Wind direction | ° | Soil depth | cm | Vegetation growth | cm/day | Water quality | ppm | Air pressure | hPa | Soil salinity | g/kg | Vegetation height | m | Water flow | m³/s | Air humidity | % | Soil temperature | °C |
| Wind frequency | times/day | Soil color | RGB | Vegetation biomass | kg/m² | Water level | m | Air quality | ppm | Soil pH | pH | Vegetation density | plants/m² | Water quality | ppm | Air temperature | °C | Soil moisture | % |
| Wind intensity | km/h | Soil texture | g/kg | Vegetation species | species/m² | Water flow | m³/s | Air humidity | % | Soil salinity | g/kg | Vegetation growth | cm/day | Water level | m | Air pressure | hPa | Soil nutrient | g/kg |
| Wind duration | h | Soil depth | cm | Vegetation color | RGB | Water quality | ppm | Air pressure | hPa | Soil salinity | g/kg | Vegetation height | m | Water flow | m³/s | Air quality | ppm | Soil moisture | % |
| Wind direction | ° | Soil color | RGB | Vegetation biomass | kg/m² | Water level | m | Air quality | ppm | Soil pH | pH | Vegetation density | plants/m² | Water quality | ppm | Air humidity | % | Soil temperature | °C |
| Wind frequency | times/day | Soil texture | g/kg | Vegetation growth | cm/day | Water flow | m³/s | Air humidity | % | Soil salinity | g/kg | Vegetation color | RGB | Water level | m | Air pressure | hPa | Soil nutrient | g/kg |
| Wind intensity | km/h | Soil depth | cm | Vegetation color | RGB | Water quality | ppm | Air pressure | hPa | Soil salinity | g/kg | Vegetation height | m | Water flow | m³/s | Air quality | ppm | Soil moisture | % |
| Wind duration | h | Soil color | RGB | Vegetation biomass | kg/m² | Water level | m | Air quality | ppm | Soil pH | pH | Vegetation density | plants/m² | Water quality | ppm | Air humidity | % | Soil temperature | °C |
| Wind direction | ° | Soil texture | g/kg | Vegetation growth | cm/day | Water flow | m³/s | Air humidity | % | Soil salinity | g/kg | Vegetation color | RGB | Water level | m | Air pressure | hPa | Soil nutrient | g/kg |
| Wind frequency | times/day | Soil depth | cm | Vegetation color | RGB | Water quality | ppm | Air pressure | hPa | Soil salinity | g/kg | Vegetation height | m | Water flow | m³/s | Air quality | ppm | Soil moisture | % |
| Wind intensity | km/h | Soil color | RGB | Vegetation biomass | kg/m² | Water level | m | Air quality | ppm | Soil pH | pH | Vegetation density | plants/m² | Water quality | ppm | Air humidity | % | Soil temperature | °C |
| Wind duration | h | Soil texture | g/kg | Vegetation growth | cm/day | Water flow | m³/s | Air humidity | % | Soil salinity | g/kg | Vegetation color | RGB | Water level | m | Air pressure | hPa | Soil nutrient | g/kg |
| Wind direction | ° | Soil depth | cm | Vegetation color | RGB | Water quality | ppm | Air pressure | hPa | Soil salinity | g/kg | Vegetation height | m | Water flow | m³/s | Air quality | ppm | Soil moisture | % |
| Wind frequency | times/day | Soil color | RGB | Vegetation biomass | kg/m² | Water level | m | Air quality | ppm | Soil pH | pH | Vegetation density | plants/m² | Water quality | ppm | Air humidity | % | Soil temperature | °C |
| Wind intensity | km/h | Soil texture | g/kg | Vegetation growth | cm/day | Water flow | m³/s | Air humidity | % | Soil salinity | g/kg | Vegetation color | RGB | Water level | m | Air pressure | hPa | Soil nutrient | g/kg |
| Wind duration | h | Soil depth | cm | Vegetation color | RGB | Water quality | ppm | Air pressure | hPa | Soil salinity | g/kg | Vegetation height | m | Water flow | m³/s | Air quality | ppm | Soil moisture | % |
| Wind direction | ° | Soil color | RGB | Vegetation biomass | kg/m² | Water level | m | Air quality | ppm | Soil pH | pH | Vegetation density | plants/m² | Water quality | ppm | Air humidity | % | Soil temperature | °C |
| Wind frequency | times/day | Soil texture | g/kg | Vegetation growth | cm/day | Water flow | m³/s | Air humidity | % | Soil salinity | g/kg | Vegetation color | RGB | Water level | m | Air pressure | hPa | Soil nutrient | g/kg |
| Wind intensity | km/h | Soil depth | cm | Vegetation color | RGB | Water quality | ppm | Air pressure | hPa | Soil salinity | g/kg | Vegetation height | m | Water flow | m³/s | Air quality | ppm | Soil moisture | % |
| Wind duration | h | Soil color | RGB | Vegetation biomass | kg/m² | Water level | m | Air quality | ppm | Soil pH | pH | Vegetation density | plants/m² | Water quality | ppm</ | | | | |



Fig. 16, 2nd row

| Descriptive statistics | | Descriptive statistics | |
|------------------------|-----------------------|------------------------|-----------------------|
| Variable | Mean (SD) | Variable | Mean (SD) |
| Age | 34.5 (10.2) | Age | 34.5 (10.2) |
| Gender | Male (70%) | Gender | Male (70%) |
| Marital status | Married (65%) | Marital status | Married (65%) |
| Education | High school (45%) | Education | High school (45%) |
| Income | \$15,000 (12,000) | Income | \$15,000 (12,000) |
| Health status | Good (75%) | Health status | Good (75%) |
| Stress level | High (60%) | Stress level | High (60%) |
| Life satisfaction | Low (55%) | Life satisfaction | Low (55%) |
| Depression | Yes (40%) | Depression | Yes (40%) |
| Alcohol use | Occasional (30%) | Alcohol use | Occasional (30%) |
| Smoking | Smoker (50%) | Smoking | Smoker (50%) |
| Exercise | Regular (20%) | Exercise | Regular (20%) |
| Family size | 3 children (40%) | Family size | 3 children (40%) |
| Work hours | 40 hours (10 hours) | Work hours | 40 hours (10 hours) |
| Job satisfaction | Low (50%) | Job satisfaction | Low (50%) |
| Health insurance | Private (60%) | Health insurance | Private (60%) |
| Medical history | Chronic (35%) | Medical history | Chronic (35%) |
| Medication | Yes (30%) | Medication | Yes (30%) |
| Comorbidities | Yes (45%) | Comorbidities | Yes (45%) |
| Genetics | Family history (25%) | Genetics | Family history (25%) |
| Environment | Urban (55%) | Environment | Urban (55%) |
| Social support | Low (40%) | Social support | Low (40%) |
| Life events | Recent (30%) | Life events | Recent (30%) |
| Personality | Extroverted (45%) | Personality | Extroverted (45%) |
| Resilience | Low (35%) | Resilience | Low (35%) |
| Coping strategies | Problem-focused (50%) | Coping strategies | Problem-focused (50%) |
| Emotional regulation | Difficult (40%) | Emotional regulation | Difficult (40%) |
| Self-efficacy | Low (30%) | Self-efficacy | Low (30%) |
| Optimism | Low (35%) | Optimism | Low (35%) |
| Gratitude | Low (30%) | Gratitude | Low (30%) |
| Forgiveness | Low (35%) | Forgiveness | Low (35%) |
| Empathy | Low (30%) | Empathy | Low (30%) |
| Compassion | Low (35%) | Compassion | Low (35%) |
| Kindness | Low (30%) | Kindness | Low (30%) |
| Generosity | Low (35%) | Generosity | Low (35%) |
| Patience | Low (30%) | Patience | Low (30%) |
| Self-control | Low (35%) | Self-control | Low (35%) |
| Impulse control | Low (30%) | Impulse control | Low (30%) |
| Emotional stability | Low (35%) | Emotional stability | Low (35%) |
| Neuroticism | High (60%) | Neuroticism | High (60%) |
| Extraversion | Low (30%) | Extraversion | Low (30%) |
| Conscientiousness | Low (35%) | Conscientiousness | Low (35%) |
| Agreeableness | Low (30%) | Agreeableness | Low (30%) |
| Openness | Low (35%) | Openness | Low (35%) |
| Intelligence | Low (30%) | Intelligence | Low (30%) |
| Memory | Low (35%) | Memory | Low (35%) |
| Attention | Low (30%) | Attention | Low (30%) |
| Perception | Low (35%) | Perception | Low (35%) |
| Emotion | Low (30%) | Emotion | Low (30%) |
| Behavior | Low (35%) | Behavior | Low (35%) |
| Thought | Low (30%) | Thought | Low (30%) |
| Feeling | Low (35%) | Feeling | Low (35%) |
| Desire | Low (30%) | Desire | Low (30%) |
| Will | Low (35%) | Will | Low (35%) |
| Power | Low (30%) | Power | Low (30%) |
| Love | Low (35%) | Love | Low (35%) |
| Kindness | Low (30%) | Kindness | Low (30%) |
| Generosity | Low (35%) | Generosity | Low (35%) |
| Patience | Low (30%) | Patience | Low (30%) |
| Self-control | Low (35%) | Self-control | Low (35%) |
| Impulse control | Low (30%) | Impulse control | Low (30%) |
| Emotional stability | Low (35%) | Emotional stability | Low (35%) |
| Neuroticism | High (60%) | Neuroticism | High (60%) |
| Extraversion | Low (30%) | Extraversion | Low (30%) |
| Conscientiousness | Low (35%) | Conscientiousness | Low (35%) |
| Agreeableness | Low (30%) | Agreeableness | Low (30%) |
| Openness | Low (35%) | Openness | Low (35%) |
| Intelligence | Low (30%) | Intelligence | Low (30%) |
| Memory | Low (35%) | Memory | Low (35%) |
| Attention | Low (30%) | Attention | Low (30%) |
| Perception | Low (35%) | Perception | Low (35%) |
| Emotion | Low (30%) | Emotion | Low (30%) |
| Behavior | Low (35%) | Behavior | Low (35%) |
| Thought | Low (30%) | Thought | Low (30%) |
| Feeling | Low (35%) | Feeling | Low (35%) |
| Desire | Low (30%) | Desire | Low (30%) |
| Will | Low (35%) | Will | Low (35%) |
| Power | Low (30%) | Power | Low (30%) |
| Love | Low (35%) | Love | Low (35%) |
| Kindness | Low (30%) | Kindness | Low (30%) |
| Generosity | Low (35%) | Generosity | Low (35%) |
| Patience | Low (30%) | Patience | Low (30%) |
| Self-control | Low (35%) | Self-control | Low (35%) |
| Impulse control | Low (30%) | Impulse control | Low (30%) |
| Emotional stability | Low (35%) | Emotional stability | Low (35%) |
| Neuroticism | High (60%) | Neuroticism | High (60%) |
| Extraversion | Low (30%) | Extraversion | Low (30%) |
| Conscientiousness | | | |



Fig. 16, 3rd row

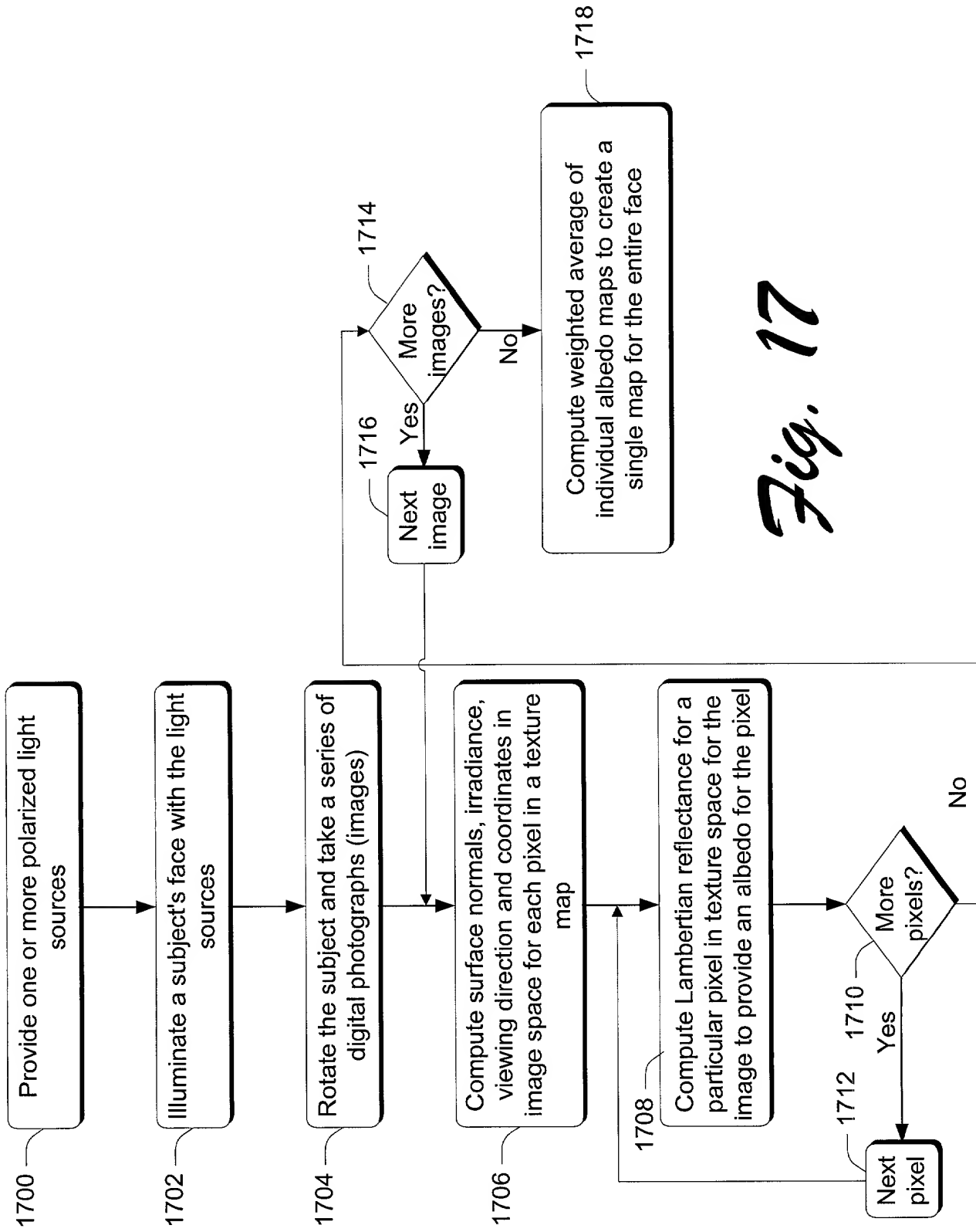
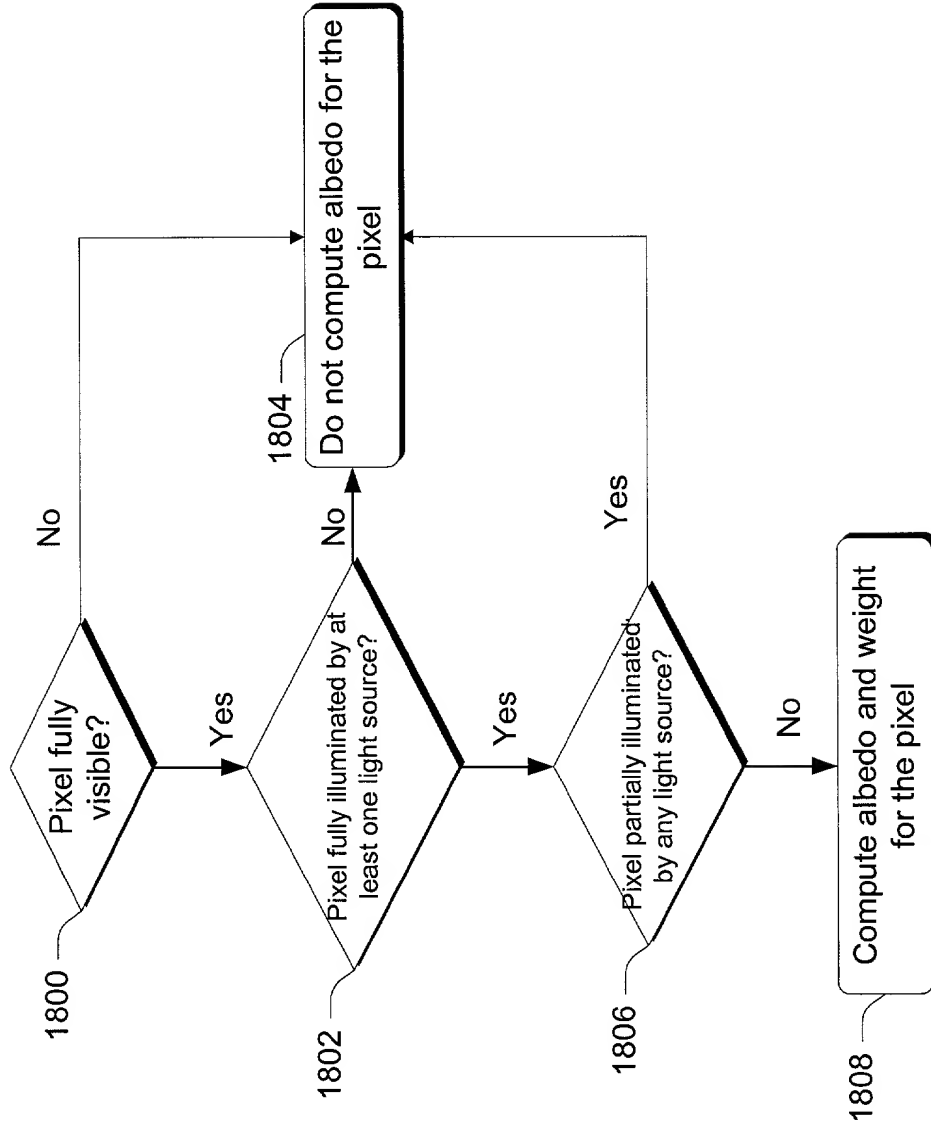


Fig. 17

*Fig. 18*

1 **IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

2 Inventorship Marschner et al.
3 Applicant Microsoft Corporation
4 Attorney's Docket No. MS1-546US
5 Title: Methods and Systems for Animating Facial Features, and Methods and
6 Systems for Expression Transformation

7 **DECLARATION FOR PATENT APPLICATION**

8 As a below named inventor, I hereby declare that:

9 My residence, post office address and citizenship are as stated below next to
10 my name.

11 I believe I am the original, first and sole inventor (if only one name is listed
12 below) or an original, first and joint inventor (if plural names are listed below) of the
13 subject matter which is claimed and for which a patent is sought on the invention
14 entitled "Methods and Systems for Animating Facial Features, and Methods and
15 Systems for Expression Transformation," the specification of which is attached
16 hereto.

17 I have reviewed and understand the content of the above-identified
18 specification, including the claims.

19 I acknowledge the duty to disclose information which is material to the
20 examination of this application in accordance with Title 37, Code of Federal
21 Regulations, § 1.56(a).

22 PRIOR FOREIGN APPLICATIONS: no applications for foreign patents or
23 inventor's certificates have been filed prior to the date of execution of this
24 declaration.

25 **Power of Attorney**

 I appoint the following attorneys to prosecute this application and transact all
future business in the Patent and Trademark Office connected with this application:

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3 Banowsky, Reg. No. 37,773; Lance R. Sadler, Reg. No. 38,605; Michael A. Proksch,
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5 42,905; Kasey C. Christie, Reg. No. 40,559; Nathan R. Rieth, Reg. No. 44,302;
6 Katie E. Sako, Reg. No. 32,628 and Daniel D. Crouse, Reg. No. 32,022.

7 Send correspondence to: LEE & HAYES, PLLC, 421 W. Riverside Avenue,
8 Suite 500, Spokane, Washington, 99201. Direct telephone calls to: Lance R. Sadler
9 (509) 324-9256.

10
11 All statements made herein of my own knowledge are true and that all
12 statements made on information and belief are believed to be true; and further that
13 these statements were made with the knowledge that willful false statements and the
14 like so made are punishable by fine or imprisonment, or both, under Section 1001 of
15 Title 18 of the United States Code and that such willful false statement may
16 jeopardize the validity of the application or any patent issued therefrom.

17
18 * * * * *

19 Full name of inventor: Stephen Marschner

20 Inventor's Signature



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Inventor's Signature

Date: _____

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Full name of inventor:

Kirk Olynyk

Inventor's Signature

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Sing Bing Kang

Date: _____

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Malaysia

18217 NE 100th Ct.
Redmond, WA 98052

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1 **IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

2 Inventorship Marschner et al.
3 Applicant Microsoft Corporation
4 Attorney's Docket No. MS1-546US
5 Title: Methods and Systems for Animating Facial Features, and Methods and
6 Systems for Expression Transformation

7 **DECLARATION FOR PATENT APPLICATION**

8 As a below named inventor, I hereby declare that:

9 My residence, post office address and citizenship are as stated below next to
10 my name.

11 I believe I am the original, first and sole inventor (if only one name is listed
12 below) or an original, first and joint inventor (if plural names are listed below) of the
13 subject matter which is claimed and for which a patent is sought on the invention
14 entitled "Methods and Systems for Animating Facial Features, and Methods and
15 Systems for Expression Transformation," the specification of which is attached
16 hereto.

17 I have reviewed and understand the content of the above-identified
18 specification, including the claims.

19 I acknowledge the duty to disclose information which is material to the
20 examination of this application in accordance with Title 37, Code of Federal
21 Regulations, § 1.56(a).

22 PRIOR FOREIGN APPLICATIONS: no applications for foreign patents or
23 inventor's certificates have been filed prior to the date of execution of this
24 declaration.

25 **Power of Attorney**

 I appoint the following attorneys to prosecute this application and transact all
 future business in the Patent and Trademark Office connected with this application:

Full name of inventor:

Brian K. Guenter

Inventor's Signature

Brian K. Guenter Date: 15 Aug 2000

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Full name of inventor:

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Inventor's Signature

Kirk Olynky Date: 8/28/2000

Residence:

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Sing Bing Kang

DoBom Date: 8/15/00

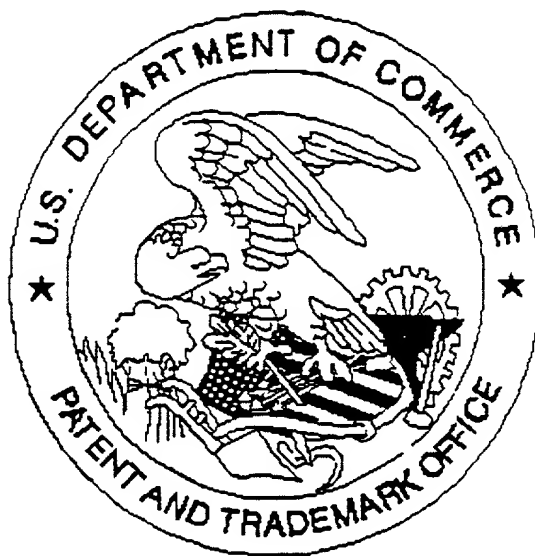
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